WCAP 9788
CLASS 3

TENSILE AND TOUGHNESS PROPERTIES OF PRIMARY PIPING WELD METAL FOR USE IN MECHANISTIC FRACTURE EVALUATION

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TENSILE AND TOUGHNESS PROPERTIES OF PRIMARY PIPING WELD METAL FOR USE IN MECHANISTIC FRACTURE EVALUATION

Executive Summary

Presently, the Loss of Coolant Accident (LOCA) evaluation of Pressurized Water Reactor (PWR) primary coolant system is carried out by postulating nonmechanistic circumferential (guillotine) breaks in which the pipe is assumed to rupture along the full circumference of the pipe. This results in overly-conservative loading conditions for the primary coolant system. Such a nonmechanistically derived conservative loading not only increases the cost of design, fabrication and maintenance, but also causes fictitious problems for the reactor coolant supports in existing plants. It is, therefore, desirable to be conservative but more realistic in the postulation of breaks for primary system design.

The following group of utilities have therefore sponsored a Mechanistic Fracture Evaluation Investigation of Reactor Coolant Pipe Materials:

American Electric Power	Donald C. Cook 1 & 2
Carolina Power & Light	Robinson 2
Commonwealth Edison	Zion 1 and 2
Connecticut Yankee	Haddam Neck
Florida Power & Light	Turkey Point 3 & 4
Rochester Gas & Elec. Co.	R. E. Ginna
Southern California Edison	San Onofre
Virginia Electric Power Co.	Surry 1 & 2
Wisconsin Electric Power	Point Beach 1 & 2
Swedish State Power	Ringhals 2
Yankee Atomic Electric Co.	Yankee Rowe
Omaha Public Power District	Fort Calhoun 1

The objective of this investigation is to examine mechanistically, under realistic and yet conservative assumptions, whether a crack assumed to appear instantaneously in these plants will become unstable and lead to a full circumferential break when subjected to the worst possible combination of plant loadings.

A detailed mechanistic evaluation, presented in WCAP-9558, for base metal has shown that double ended breaks of reactor coolant pipes are unrealistic and, as a result, large LOCA loads on primary system components will not occur.

This report presents the results of an investigation undertaken to determine the tensile and fracture toughness of representative reactor coolant system weld samples. The results of the tensile and fracture toughness tests are summarized and the weld metal properties are compared with the same properties of the base metal. It is found that the weld metal properties fall within or above the scatter band of the properties of the base metal. Therefore the conclusions reached in WCAP-9558 for base metal are equally applicable to weld metal.

1. INTRODUCTION

a,c

this report is to present the tensile and fracture toughness properties for the weld metal and to show that the conclusions reached for the base metal are equally applicable to the weld metal.

The weld metal test program, which was undertaken to obtain the tensile and fracture toughness properties for weldments representative of those found in the plants listed in Table 1-1 consisted of several steps. First, a survey was conducted to identify the various welds in the primary coolant system of each of the affected plants. The weld procedures were reviewed and summarized. Second, a test program was formulated to represent the conditions identified in the weld data survey. Third, the various weld specimens were fabricated to the applicable specifications. Fourth, tensile and compact tension specimens were machined and tested to obtain the required material properties for comparison with the base metal properties.

Each of the above steps are briefly discussed in the following sections. The results of the tensile and fracture toughness tests are summarized

a,c

1. Palusamy, S. S. and Hartmann, A. J., Mechanistic Fracture Evaluation of Reactor Coolant Pipe Containing a Postulated Circumferential Through-Wall Crack, WCAP 9558 - Rev. 2, Proprietary Class 2, May 1981.

TABLE 1-1

PLANTS COVERED IN THIS REPORT

PLANT	IDENTIFICATION Acronyms	OWNER UTILITY
Donald C. Cook 1 & 2	AEP, AMP	American Electric Power
Robinson 2	CPL	Carolina Power & Light
Zion 1 and 2	CWE, COM	Commonwealth Edison
Haddam Neck	CYW	Connecticut Yankee
Turkey Point 3 & 4	FPL, FLA	Florida Power & Light
R. E. Ginna	RGE	Rochester Gas & Elec. Co.
San Onofre	SCE	Southern California Edison
Surry 1 & 2	VPA, VIR	Virginia Electric Power Co.
Point Beach 1 & 2	WEP, WIS	Wisconsin Electric Power
Ringhals 2	SSP	Swedish State Power
Yankee Rowe	YR	Yankee Atomic Electric Co.
Fort Calhoun 1	OPPD	Omaha Public Power District

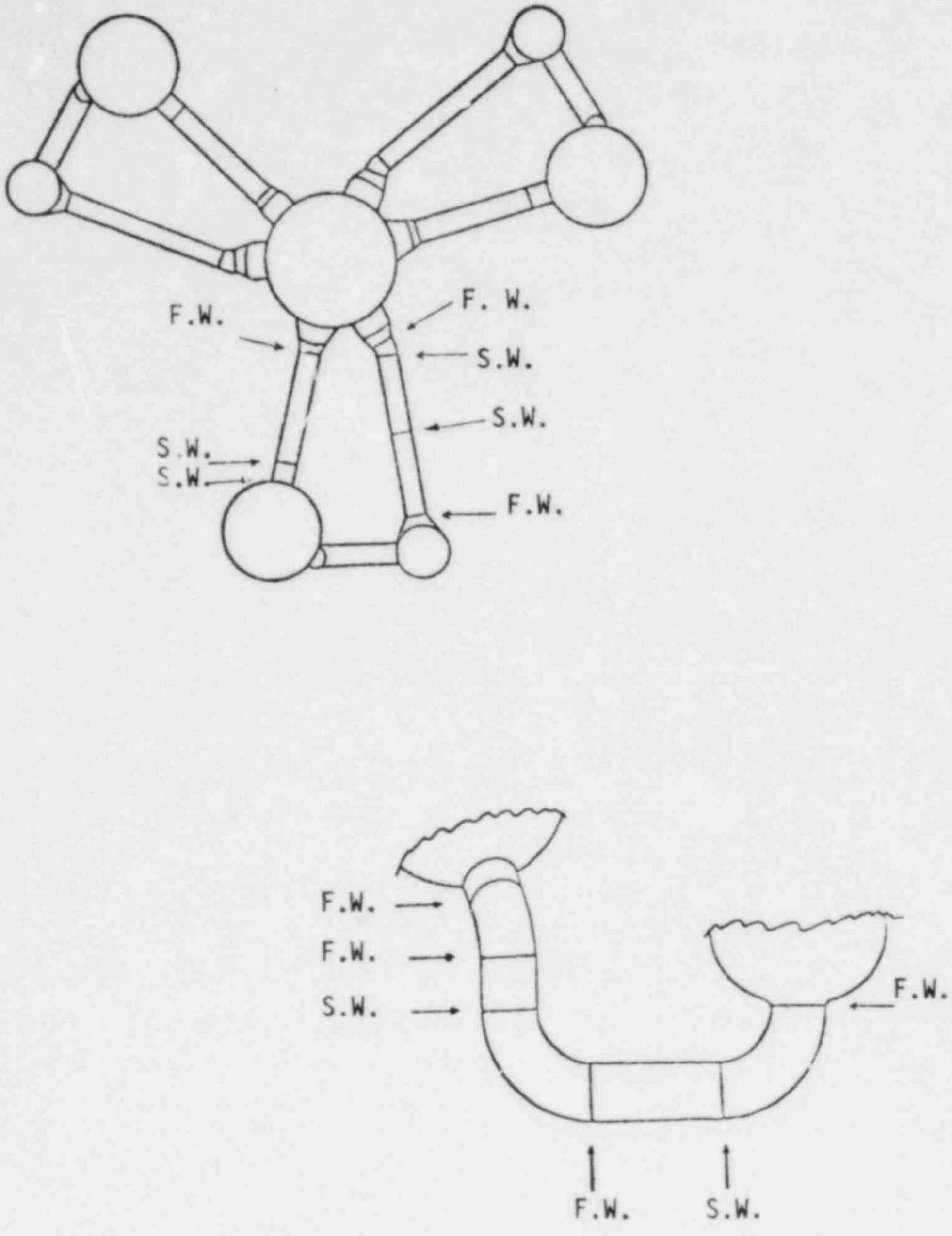

FIGURE 2-2 Weld location for Robinson Unit 2

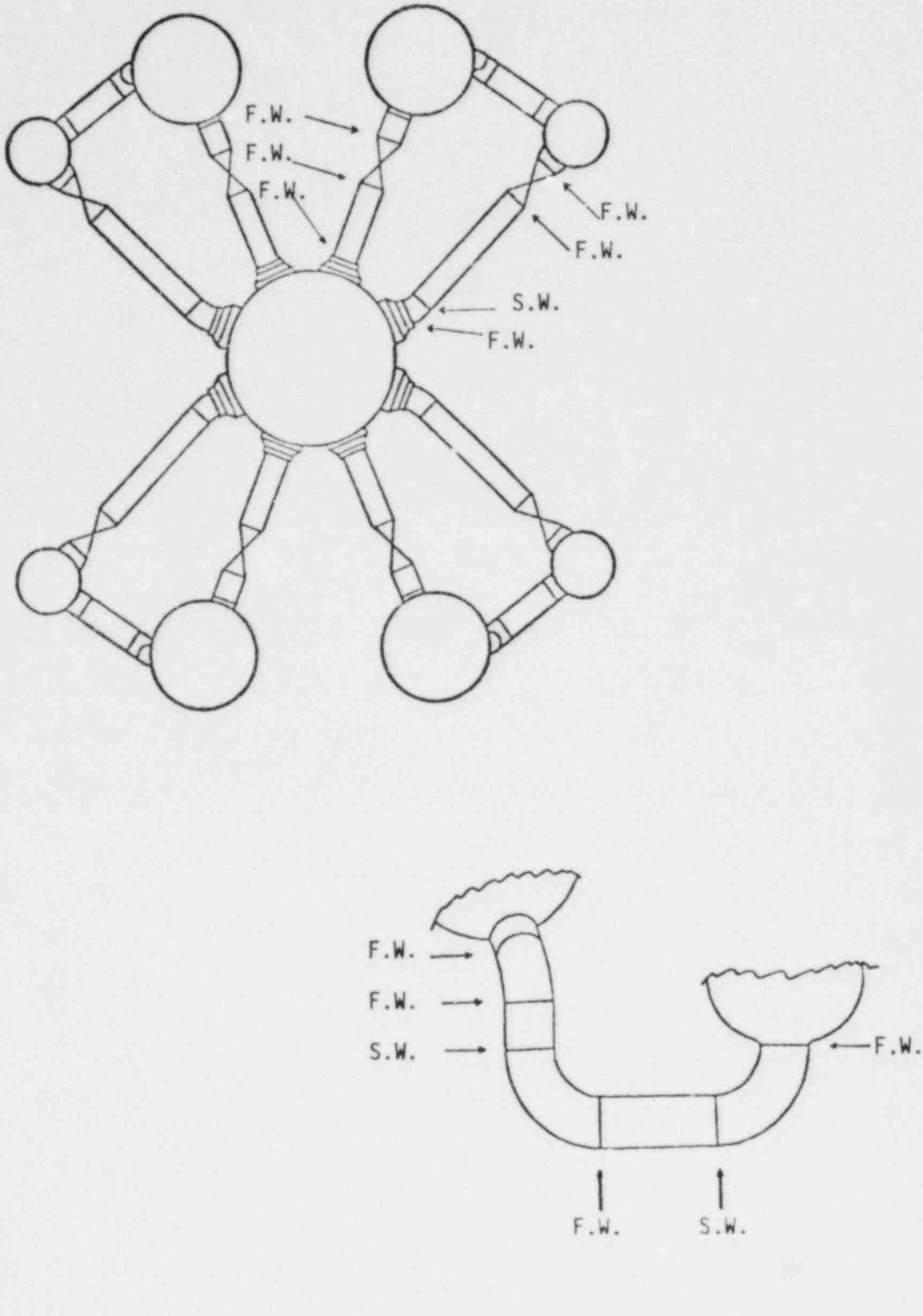

FIGURE 2-3   Weld location for Zion Units 1 and 2

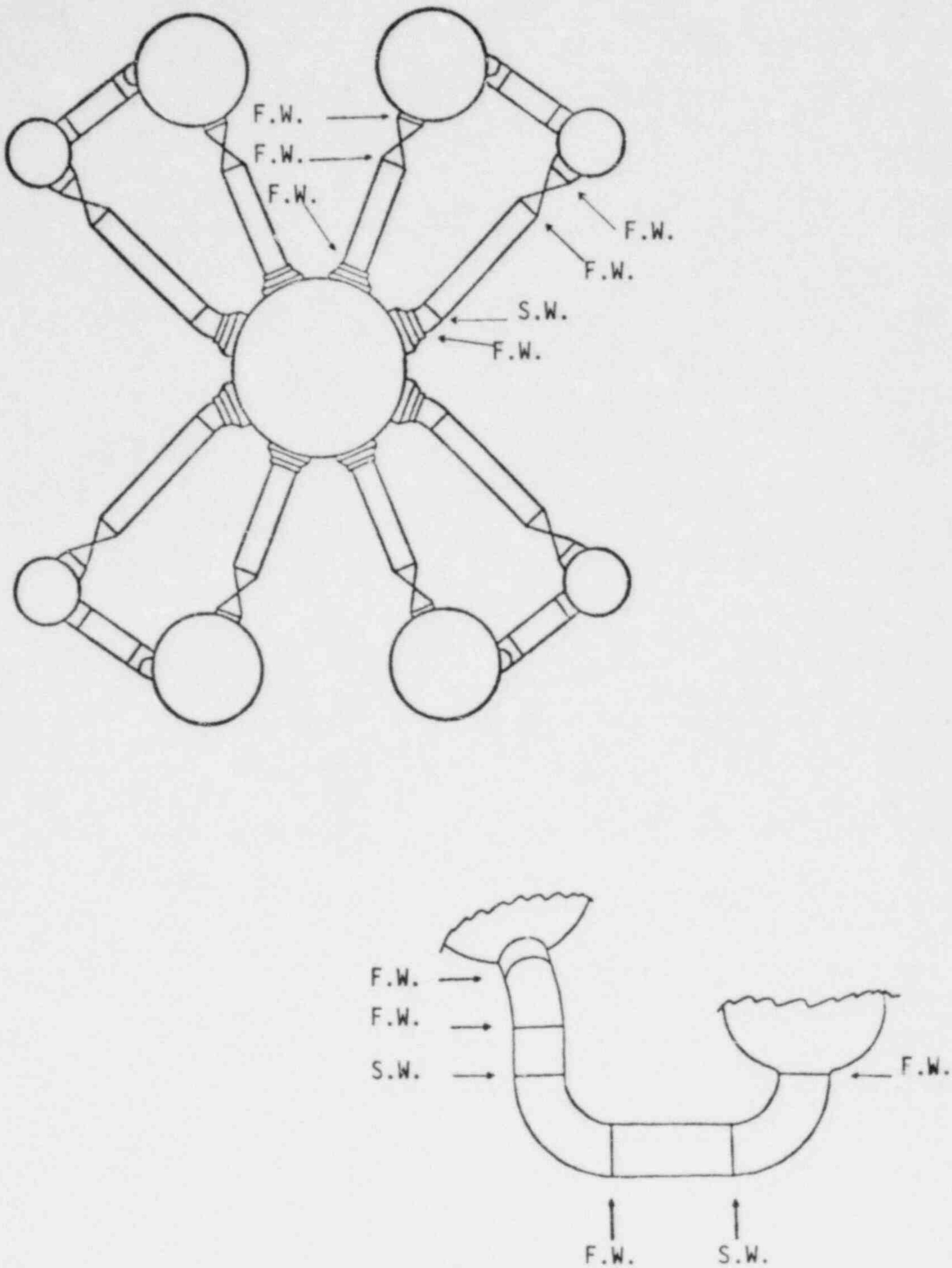

FIGURE 2-4 Weld Location for Haddam Neck Unit

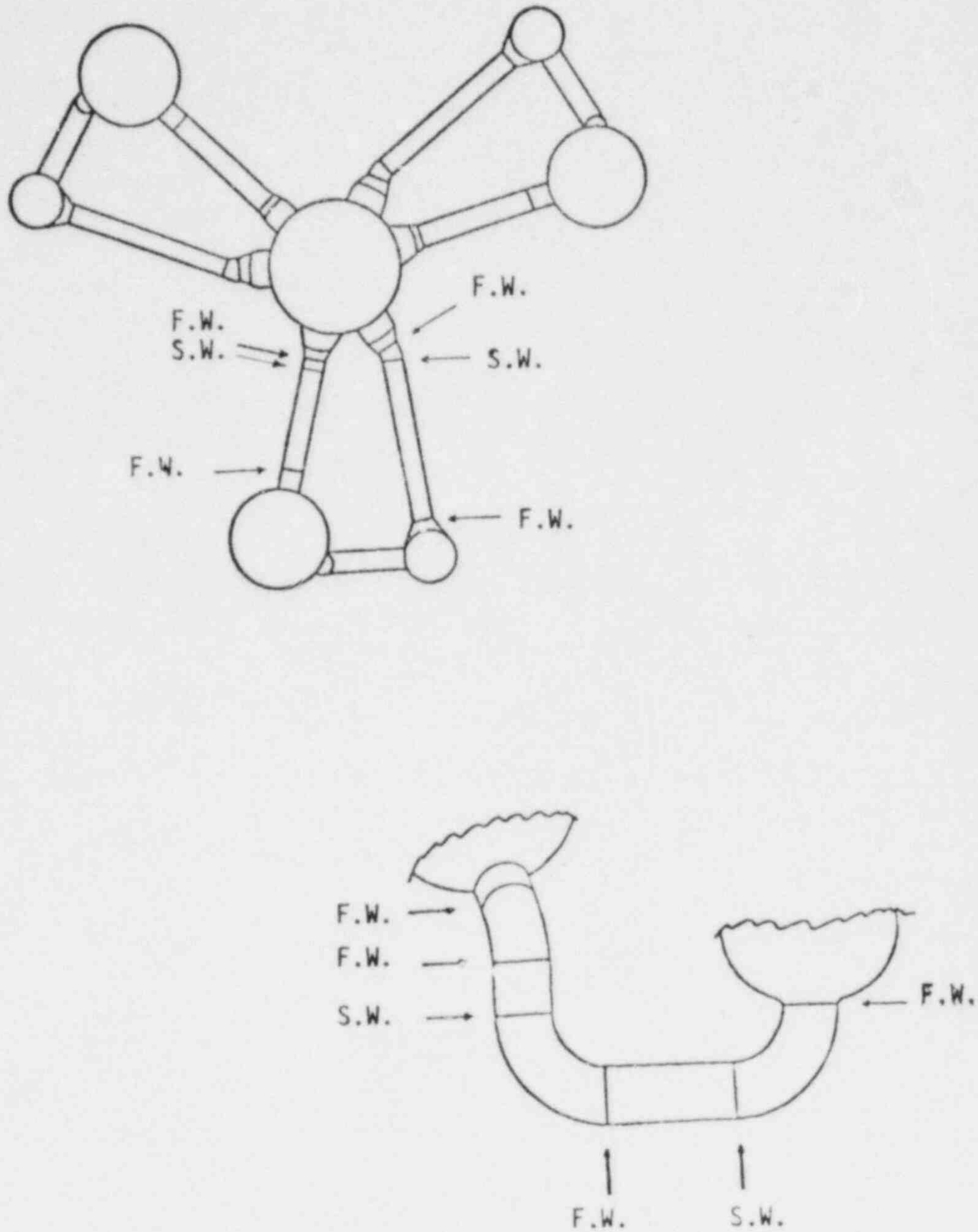

FIGURE 2-5 Weld location for Turkey Point Units 3 and 4

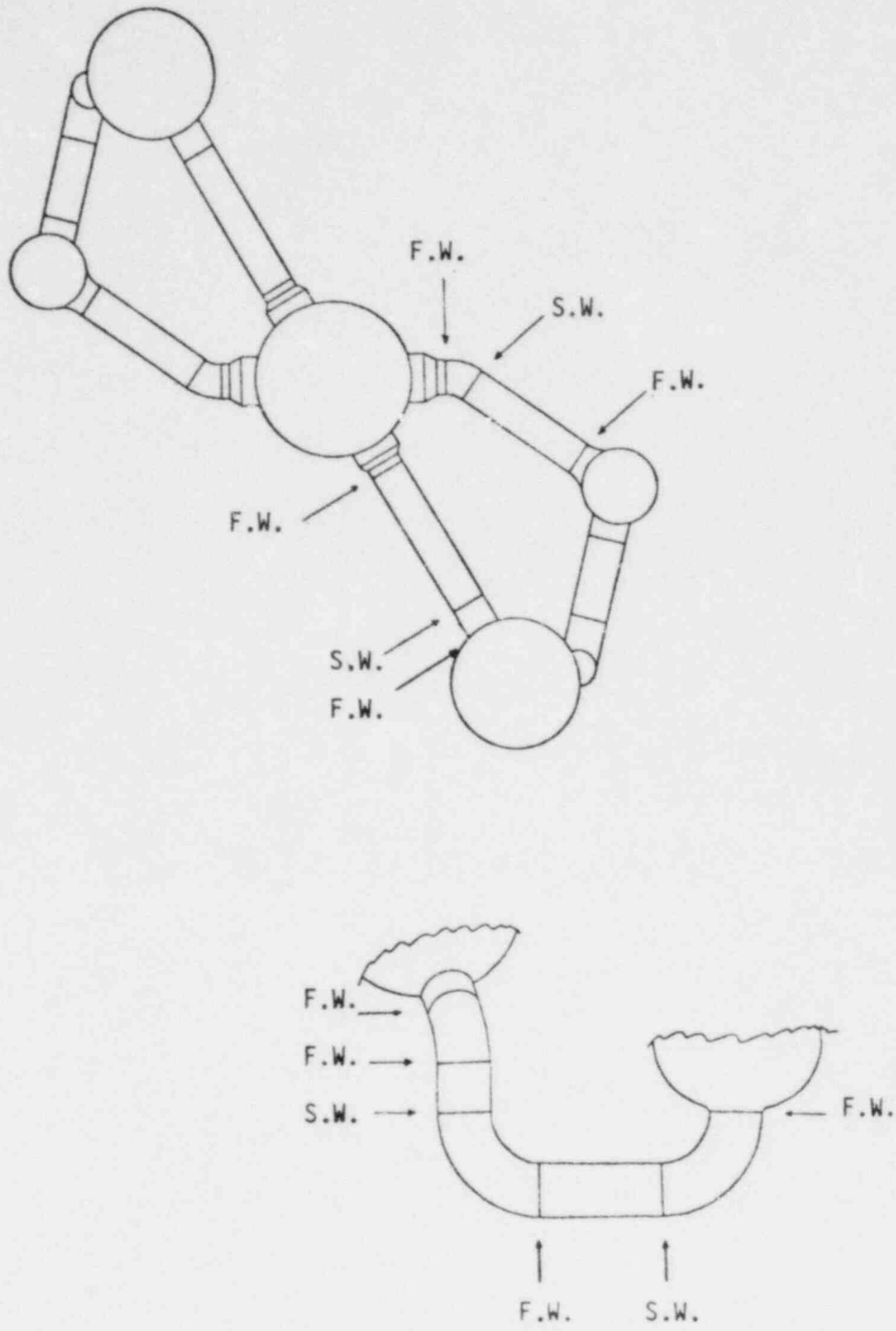

FIGURE 2-6 Weld location for R.E. Ginna Unit

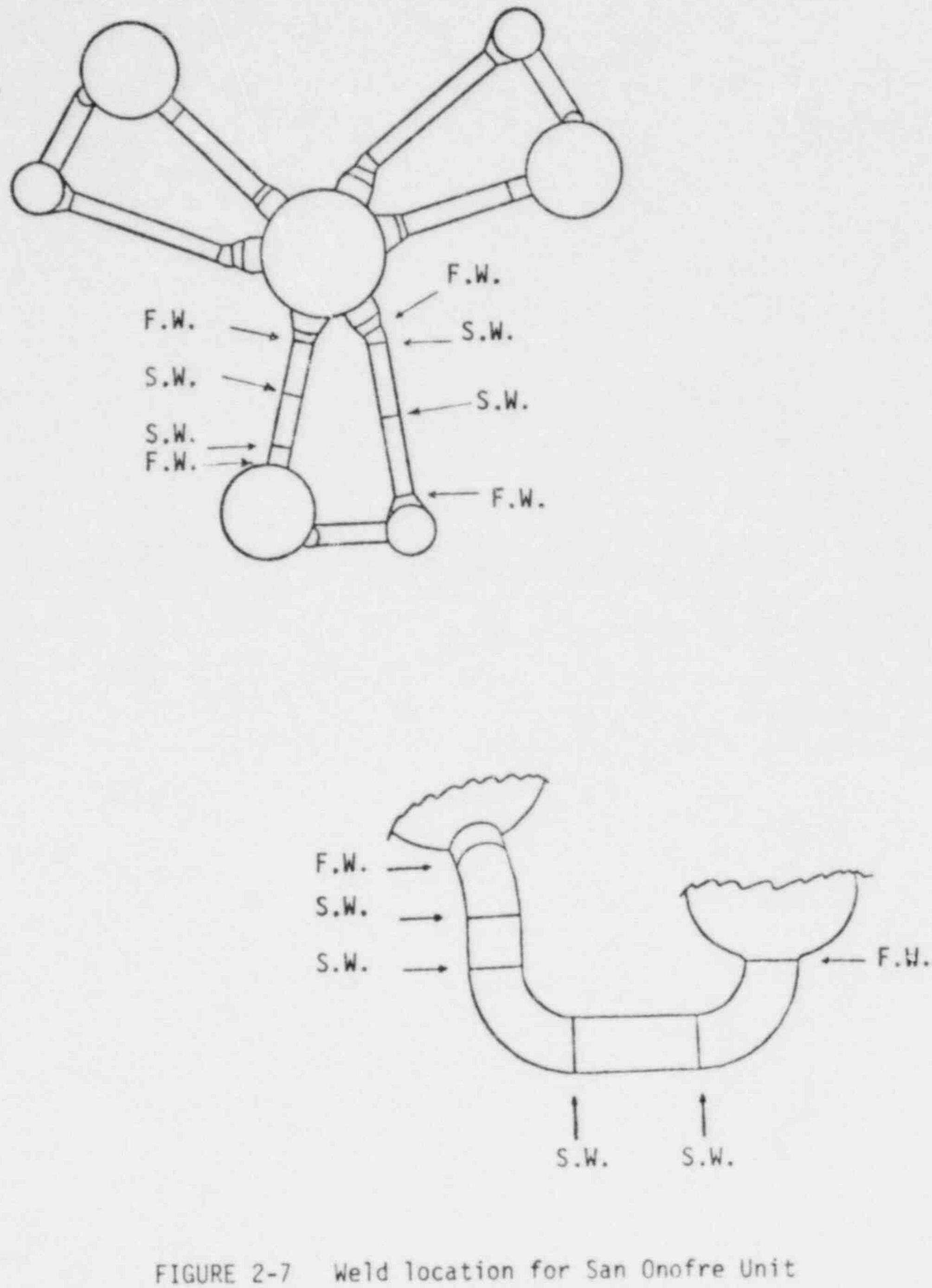

FIGURE 2-7 Weld location for San Onofre Unit

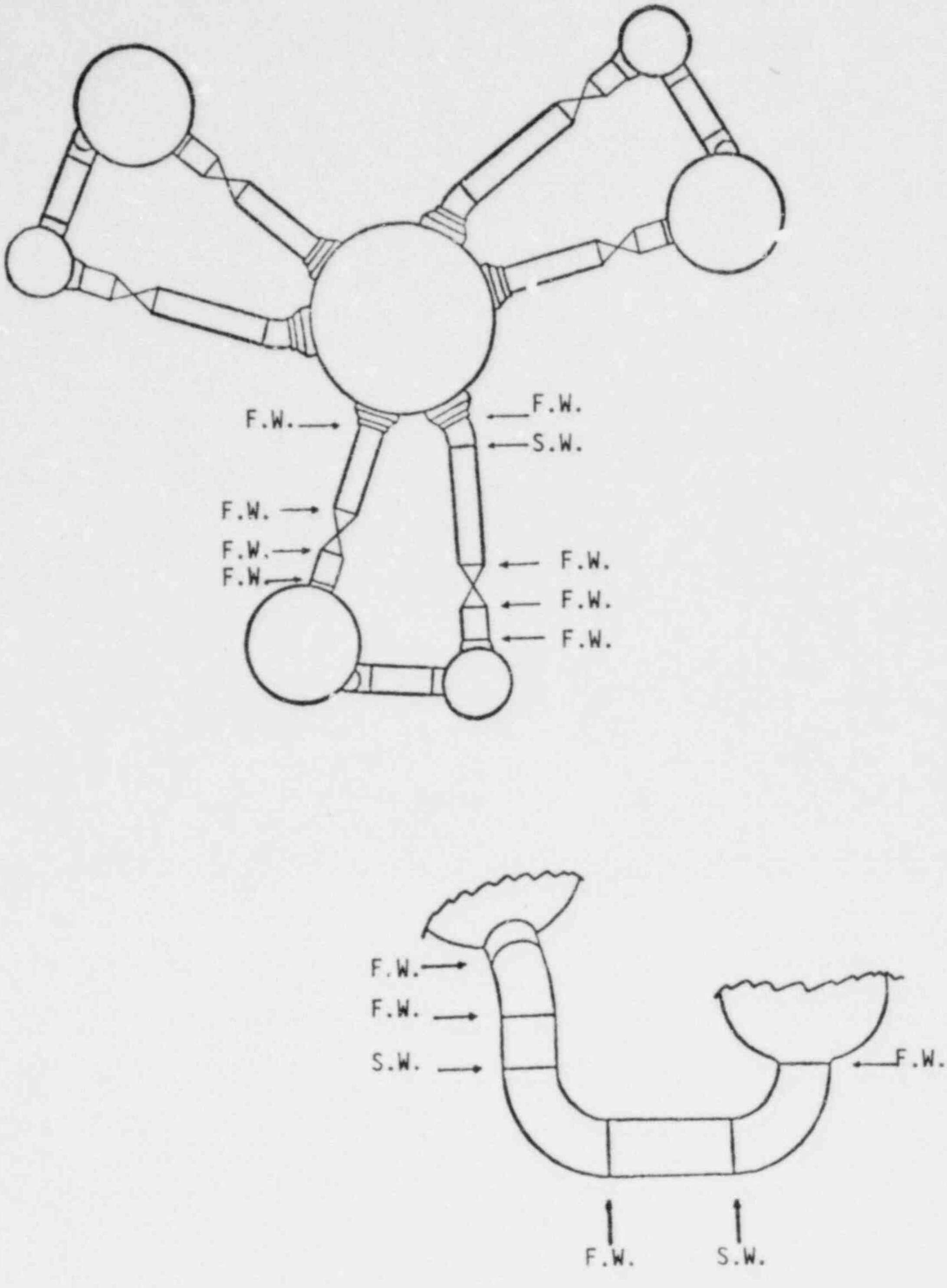

FIGURE 2-8 Weld location for Surry Units 1 and 2

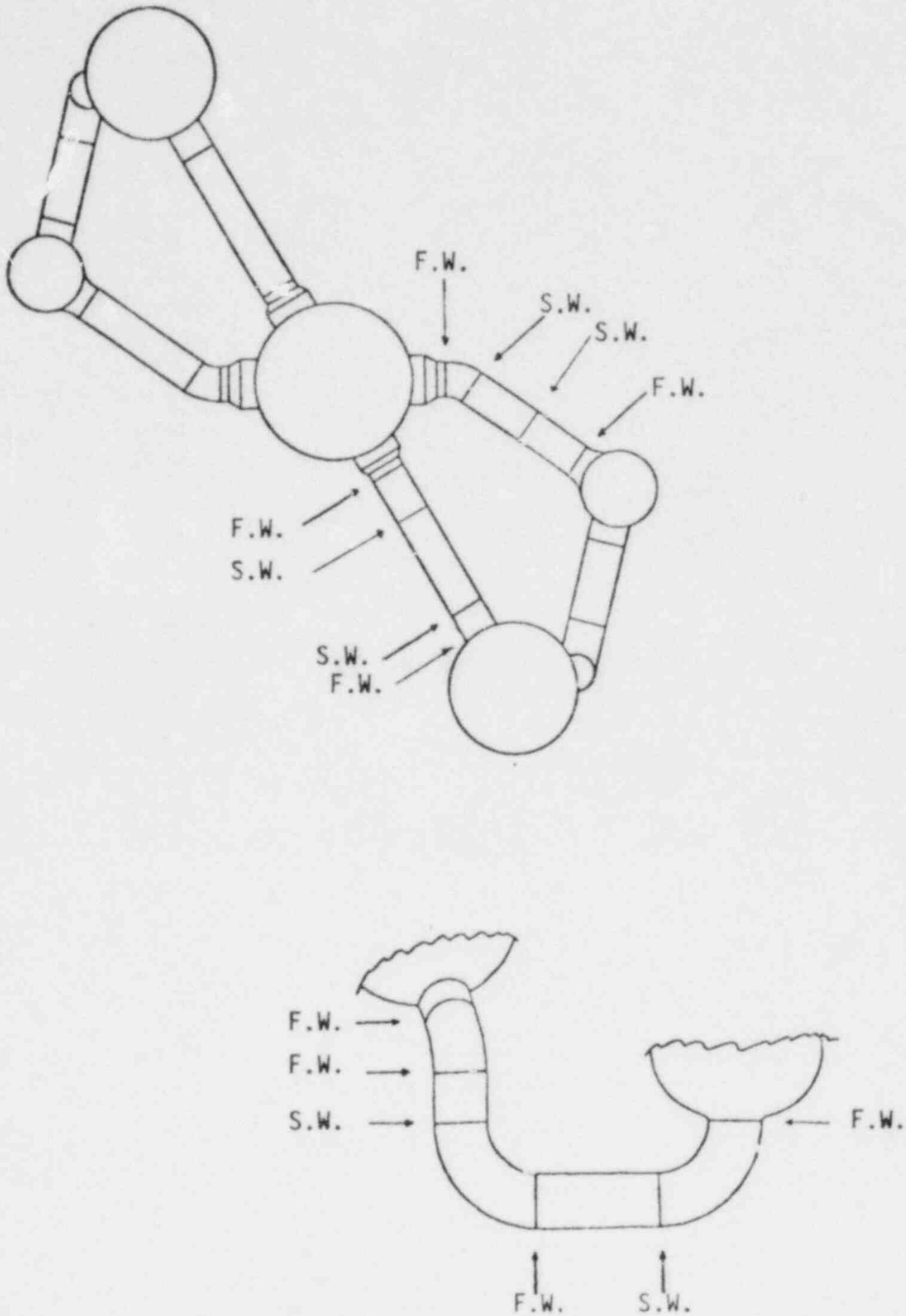

FIGURE 2-9 Weld location for Point Beach Units 1 and 2

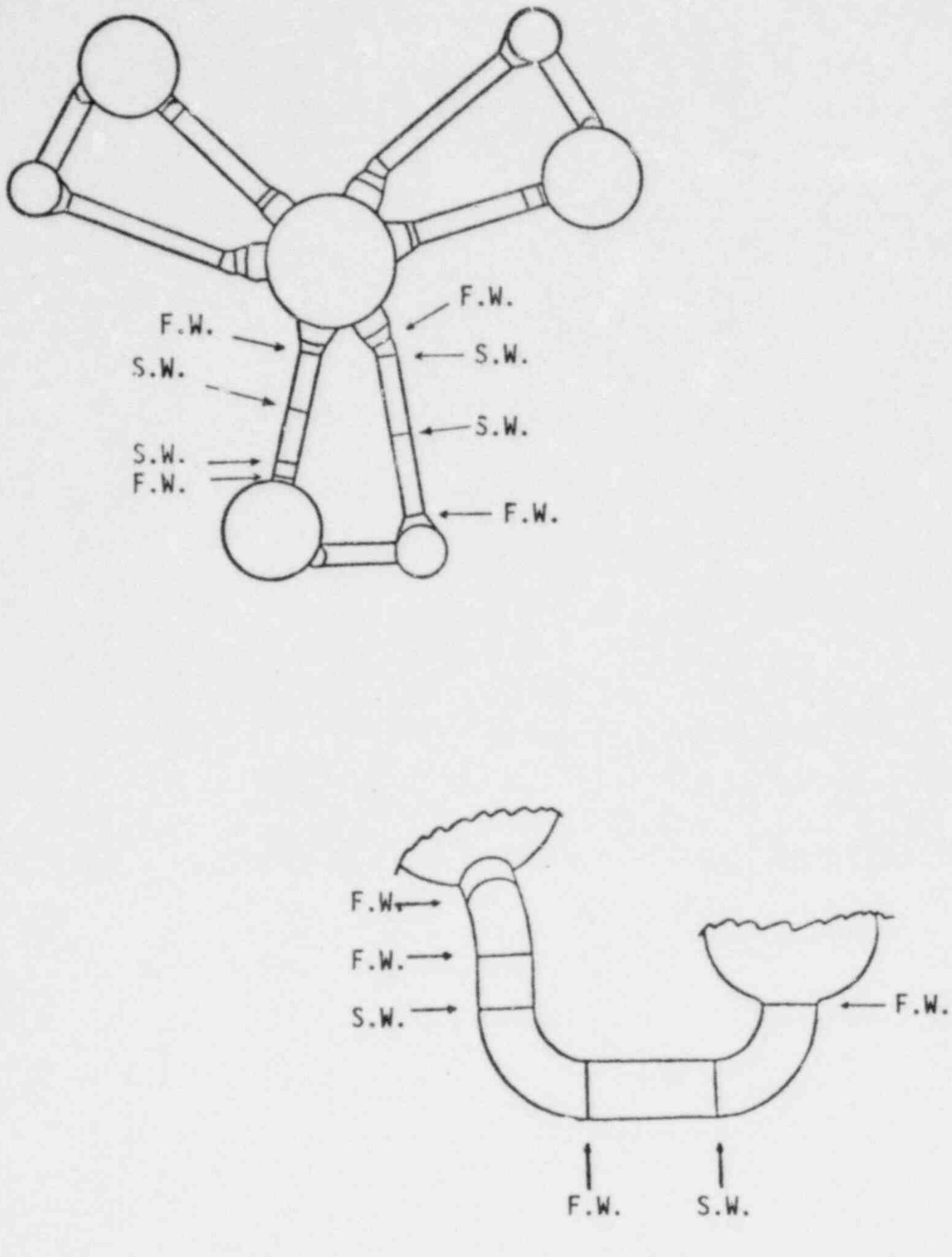

FIGURE 2-10 Weld location for Ringhals Unit 2

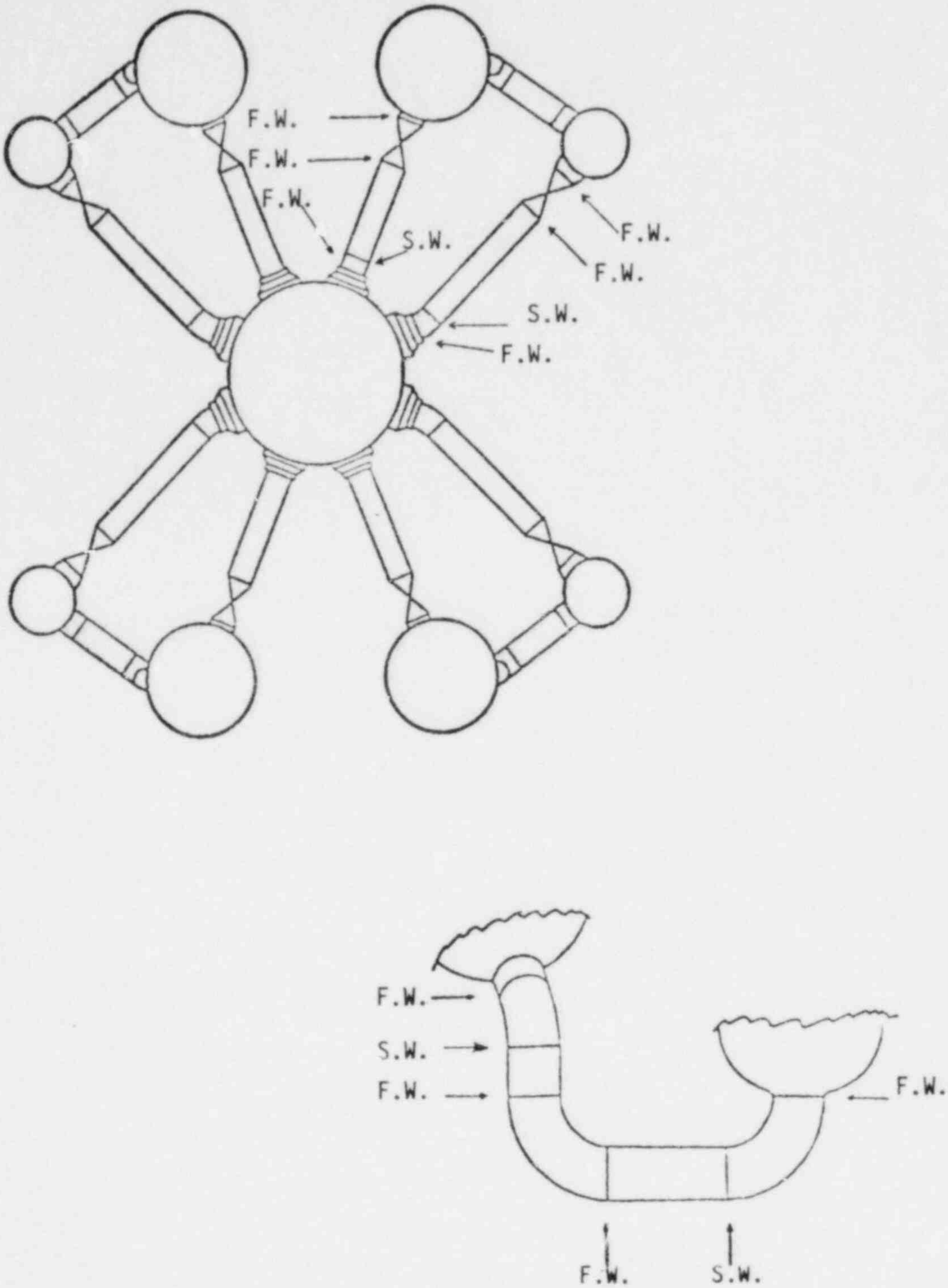

FIGURE 2-11 Weld location for Yankee Rowe Unit

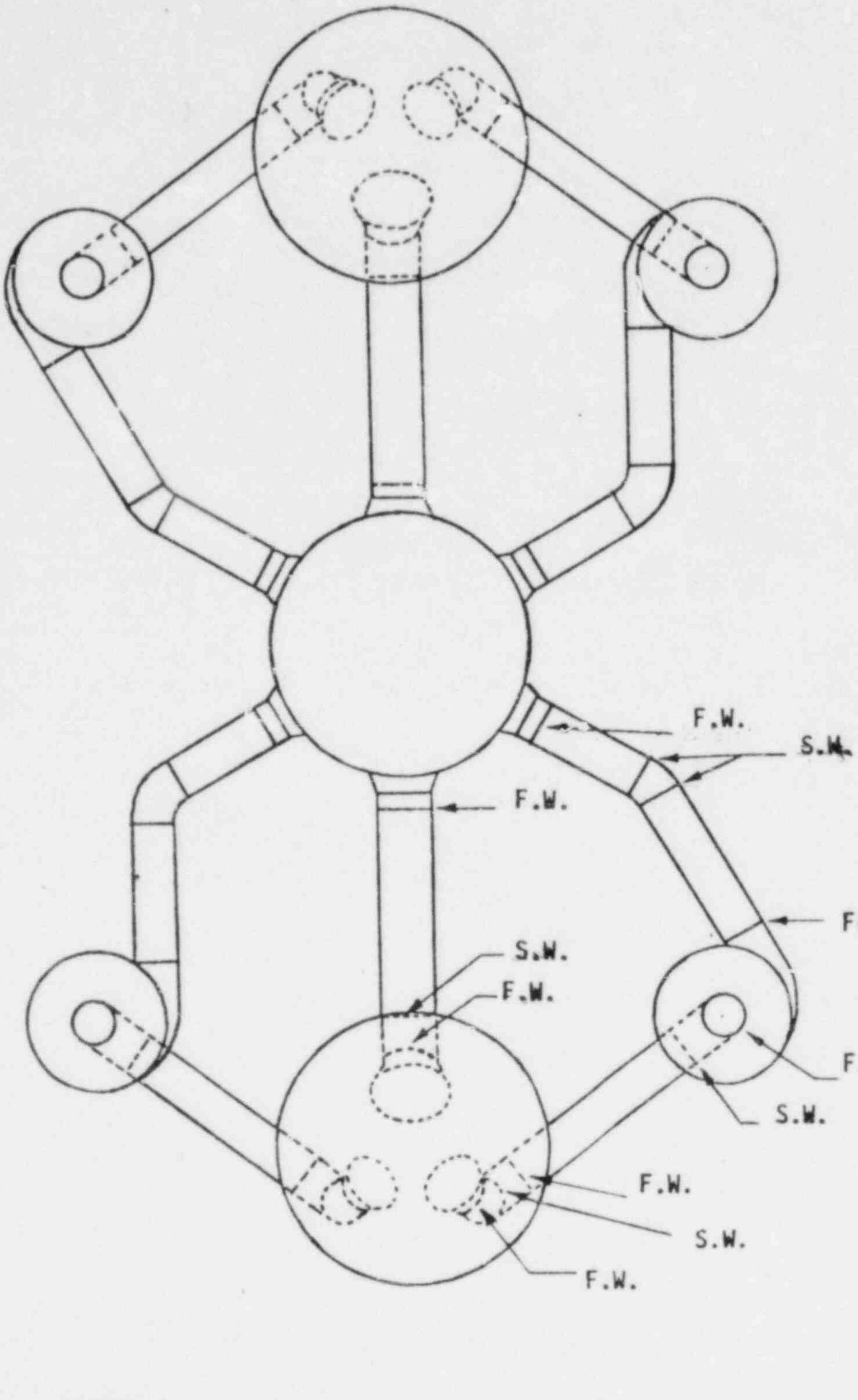

FIGURE 2-12 Weld location for Fort Calhoun Unit 1

TABLE 2-1 SUMMARY OF REACTOR VESSEL SAFE END WELD DETAILS

Plant	Vendor and Contract #	Safe End Design	Nozzle	Dwg. No.	Weld No.	Weld Proc. No.	Weld Process	Weld Metal		Overlay Weld Metal	Weld Process for Overlay	Exposed Sensitized S.S. Weld Metal	Exposed Heat Treated Inconel Weld Metal
							a,c		a,c	a,c	a,c	a,c	a,c
AEP	C.E.	S.S. Safe end attached prior to final PWHT	All	E-233-445	3-445	WC-23366-							
	23366	Overlay with S.S. & inconel in shop.				445							
		After final PWHT.											
AMP	CB & I	S.S. Safe end attached prior to PWHT	All	68-3262-55	Buttering	1103-4-F5							
	68-3262	Overlayed with S.S. in shop prior to PWHT		68-3262-24	Weld	1305-6-F5							
Y-R	B&W	Nozzle ends buttered with stainless		34971E									
		steel prior to PWHT											
CWE	B&W	Nozzle ends buttered with stainless	Inlet	133325E	WR-19	WR-19 Rev.0							
	610-0144	steel prior to PWHT	Outlet	133322E	WR-23	WR-23 Rev.0							
CGM	B&W	Nozzle ends buttered with stainless	Inlet	139749E	WR-19	WR-19 Rev.0							
	610-0152	steel prior to PWHT	Outlet	139747E	WR-23	WR-23 Rev.0							
FPL	B&W	Nozzle ends buttered with stainless	Outlet	117887E	WR-27	WR 27&3							
	610-0116	steel prior to PWHT	Inlet	117886E	WR-3								
						WR 27&3 Alt. 1							
						WR 27&3 Alt. 2							
FLA	B&W	Nozzle ends buttered with stainless	Outlet	117887E	WR-27	Same as FPL							
	610-0116	steel prior to PWHT	Inlet	117886E	WR-3								

**** All weld is 308L

TABLE 2-1 (cont'd)

Plant	Vendor and Contract #	Safe End Design	Nozzle	Dwg. No.	Weld No.	Weld Proc. No.	Weld Process	Weld Metal		Overlay Weld Metal	Weld Process	Exposed Sensitized S.S. Weld Metal	Exposed Heat Treated Inconel Weld Metal
							a,c	a,c		a,c		a,c	a,c
CPL	C.E.	Stainless steel forging attached	All Buttering	E232-276	1-276	MA-8.43(7)							
	6866	prior to final PWHT	All-Weld		10-276	MA-3.43(4)							
RGE	B&W	Nozzle ends buttered with stainless	All		WR-34 Inlet	WR 34 & WR 38							
	611-0110	steel prior to final PWHT	All		WR-38 Outlet								
VPA	B&W	Nozzle ends buttered with stainless	Inlet	131185E	WR-27	WR-27 Alt.1							
	(Nozzles)	steel prior to final PWHT	Outlet	131184E	WR-3	WR-3 Alt. 1							
VIR	B&W	Nozzle ends buttered with stainless	Inlet	131185E	WR-27								
	(Nozzles)	steel prior to final PWHT	Outlet		WR-3								

TABLE 2-1 (cont'd)

Plant	Vendor and Contract #	Safe End Design	Dwg. No.	Weld No.	Weld Proc. No	Weld Process	Weld Metal		Overlay Weld Metal	Weld Process		Exposed Sensitized S.S. Weld Metal	Exposed Heat Treated Inconel Weld Metal
						a,c	a,c		a,c			a,c	a,c
WEP	B&W	Nozzle ends buttered with stainless	Inlet 117820E	WR-34	WR-34								
	610-0115	steel prior to final PWHT	Outlet	WR-38	WR-38								
			117825E										
WIS	B&W (C.E.)	Nozzle ends buttered with stainless			C.E.-SAA-699								
	(Nozzles)	steel prior to final PWHT	E-233-686		B&W-								
SCE	C.E.	Nozzles buttered prior to final PWHT	E-201-863	1-863	MA-3.43E(4)								
	2461	S.S. forging attached after final PWHT		3-863	MA-8.43C(7)								
CYW	C.E.	Nozzles buttered prior to final PWHT	E-231-376	4-376	MA-3.43E(4)								
	263	S.S. forging attached after final PWHT		2-376	MA-8.43C(7)								
SSP	RDM	Nozzle ends buttered with stainless	30663-1266 Sht. 2	Inlet	RDM 36.09								
	30663	steel prior to final PWHT											
			30663-1267 Sht. 2	Outlet	RDM 36.09								
OPPD	C.E.	Stainless steel forging attached prior to final PWHT	E232-412-4	1-412 A-F	WA-711 66-412-0								

TABLE 2-2 SUMMARY OF PIPE WELD DETAILS FOR AEP AND AMP

TYPE OF WELD	Weld Process**	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
<u>Field Welds</u>										
layers:	a,c	a,c	a,c	a,c						
root pass					75/125 SP	17/22	-	-	Unit 1: Livesy Co. Unit 2: Power Systems Inc.	Pro 8-2 rev. IV
2 & 3 root pass (if req'd)					45/90 SP	14/20	-	-	↓	↓
cover or cap pass*					75/125 SP	17/22	-	-	↓	↓
1st layer after root					65/115 RP	17/22	-	-	↓	↓
2nd					65/115	17/22	-	-	↓	↓

*Livesy Co. Did not complete cover pass by GTAW.

**Argon shield and internal purge.

TABLE 2-2 SUMMARY OF PIPE WELD DETAILS FOR AEP AND AMP (cont'd)

TYPE OF WELD	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds										
layers:	a,c	a,c	a,c	a,c						
As many as required					7/125 RP 110/150RP	19/25 20/28	≈ 8 Total	RT of final weld	Unit 1: Livesy Co. Unit 2: Power Systems Inc.	Pro 8-2 rev. IV
Shop Welds										
layers:										
root pass	*				75/100 SP	13/15	~8	***	Southwest Fabricating	p-8-HA-1
2nd					80/120 RP	14/16	~8	***	↓	↓
3rd					200/300RP	28/30	~8	***	↓	↓
As many as required					275/350RP	29/32	~8	***	↓	↓

*Argon Shield

**Argon Shield and Internal Purge

***Radiographic, dipenetrant and ultrasonic procedures as applicable at various locations; inspection records for Unit 1 on file.

TABLE 2-3 SUMMARY OF PIPE WELD DETAILS FOR CPL

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds										
layers:	a,c	a,c	a,c	a,c						
1st	[ ]	[ ]	[ ]	[ ]	95/105 SP	9/12	***	**	Ebasco Combustion Eng. Navco	WP-6
2nd					70/80 RP	20/23	***	**	↓	↓
or										
2nd (alt.)					95/105 SP	9/12	***	**	↓	↓
As many as required					100/150RP	21/24	***	**	↓	↓
Final (alt.) (may be used)					100/130SP	9/12	***	**	↓	↓
SHOP WELD	SEE FIELD WELDS									

*Argon shield and internal purge.
**PT of weld root, RT of 1/3 wall, RT & PT after final pass.
***Not Available.

TABLE 2-4 Summary of Pipe Weld Details for CWE and COM

TYPE OF WELD	Weld Process *	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	[ ]a,c	[ ]a,c	[ ]a,c	[ ]a,c						
beads**:										
1					90/120SP	16/24	***	PT	Pope-Morrison	73 rev. 2
2					90/120SP	16/24	***	-	↓	↓
3-6					90/120RP	16/24	***	-	↓	↓
As many as required					100/160RP	22/25	***	PT & 100% RT	↓	↓
Shop Welds	SHOP WELDS BY SOUTHWEST FABRICATING & WELDING CO., SHOP WELDS ARE THE SAME AS AEP EXCEPT THAT: THE NUMBERS OF HEATS AND THE INSPECTION REQUIREMENTS ARE UNAVAILABLE.									

*Argon shield and internal purge.
**Number of beads varies with weld position.
***Two bare filler wire and three consumable insert heats per reactor.

TABLE 2-5 SUMMARY OF PIPE WELD DETAILS FOR CYW

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds										
layers:	a,c	a,c	a,c	a,c						
root pass	[ ]	[ ]	[ ]	[ ]	90/125 SP	14/16	**	PT	Stone & Webster	W-10899-2
As many as required					80/110/135 RP	18/22/24	**	PT & RT	↓	↓
Shop Welds	SAME AS FIELD WELDS									

*Argon shield and internal purge
**Not available

TABLE 2-6 SUMMARY OF ~~PIPE~~ WELD DETAILS FOR FLA AND FPL

TYPE OF WELD	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents*
Field Welds layers:	a,c	a,c	a,c	a,c						
1 & 2					70/120 SP 60/110 SP	10/15 10/15	***	**	Bechtel ↓	P8-AT-Ag rev 12 ↓
3					60/100 RP	22/25	***	**		
4 & 5					80/130 RP	23/26	***	**		
As many as required					80/130 RP 100/170 RP	23/26 24/27	***	**		
	OTHER CHARACTERISTICS THE SAME AS ABOVE									P8-AT-Ng rev. 12

*P8-AT-Ag - Argon shield purge, P8-AT-Ng - Argon shield and nitrogen purge.
**100% RT after final pass, PT of root and final passes.
***Not Available.

TABLE 2-6 (cont'd)

Type of Weld	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Shop Welds:	a,c	a,c	a,c	a,c					NAVCO	
Layers: Root Pass					*	*	***	PT		SW-043 W-020 Rev. 2
2nd & 3rd Pass					*	*	***	-		
**					*	*	***	PT after comp.		
To completion					400 RP	27-1/2	***	PT, RT		
					500 RP	29-1/2				

* NAVCO Specification W-020 Rev. 2

**Passes are continued until the width of weld joint is 3/4"

***Number of Heats Unknown

WESTINGHOUSE PROPRIETARY CLASS 2

TABLE 2-7 SUMMARY OF PIPE WELD DETAILS FOR RGE

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	[ ] a,c	[ ] a,c	[ ] a,c	[ ] a,c						
layers:										
root					70/150 RP	16/20	***	PT	Bechtel Corp.	P8-AT-g
2nd					70/100 RP	23/25	***	-	↓	↓
As many as required					70/100 RP or 110/130 RP**	23/25 or 24/26**	***	PT & RT after final pass		
Shop Welds	SHOP WELDS BY NAVCO - SEE TABLE 2-6.									

*Argon shield and internal purge
**Different amps & volts depended upon electrode size.
***Not Available.

TABLE 2-8 SUMMARY OF PIPE WELD DETAILS FOR SCE

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	[ ] a,c	[ ] a,c	[ ] a,c	[ ] a,c						
layers:										
1					70/150 SP	16/20	***	**	Bechtel Corp.	P8-AT-g rev. 1
					150/250 SP	20/24			↓	↓
As many as required					70/100 RP	23/25	***	**		
					110/130 RP	24/26				

*Argon shield and internal purge.
**100% RT
***Not Available.

TABLE 2-8 (cont'd)

Type of Weld	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Shop Welds:	[ ]a,c	[ ]a,c	[ ]a,c	[ ]a,c						
1st & 2nd Passes					60/80 RP	23	*	PT	DRAVO Corp.	WE-AH6-12
To completion					400 RP	30	*	RT & PT Final		

*Not Available

TABLE 2-9 SUMMARY OF PIPE WELD DETAILS FOR VPA AND VIR

TYPE OF WELD	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	a,c	a,c	a,c	a,c						
layers:										
root					60/100 SP	12 ± 2	**	*	Stone & Webster	W-100
(2 passes)										rev. 1
As many as required					50/80 RP	22 ± 2	**	*	↓	↓
					70/100 RP					

*RT and PT of root and final weld
**Not Available

TABLE 2-9 (cont'd)

Type of Weld	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Shop Weld:	a,c	a,c	a,c	a,c						
Pass No.										
1-3					100-170 SP	10-14	**	Not Given	Southwest Fab.	P-8-HM-3
					140-210 SP	16-19	**			
4-5					140-210 SP	16-19	**			
Until Completion					90-160 RP	22-25	**			
					140-210 RP	24-28	**			
					70-110 RP	22-25	**			

NOTE: Heat Treatment - None

** Not Available

TABLE 2-10 SUMMARY OF PIPE WELD DETAILS FOR WEP AND WIS

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	[ ]a,c	[ ]a,c	[ ]a,c	[ ]a,c						
layers:										
root &					60/110 SP	10/15	***	**	Bechtel Corp	P8-AT-Ag
2nd pass					70/120 SP	10/15			↓	rev. 11 ↓
1st after GTAW					60/100 RP	22/25	***	**		
2nd & 3rd					80/130 RP	23/26	***	**		
As many as required					80/130 RP 100/170 RP	23/26 24/27	***	**		
Shop Welds	SHOP WELDS BY NAVCO, SEE TABLE 2-6.									

*Argon shield and internal purge.
**100% RT, and PT of root and final passes.
***Not Available

TABLE 2-11 SUMMARY OF PIPE WELD DETAILS FOR SSP

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds	a,c	a,c	a,c	a,c						
pass:										
1					60/100 SP	18/24	***	**	Mannesmann Rohrbau(Germany)	34
2 & 3					60/100 SP	18/24	***	**	↓	↓
4					70/100 RP	24/30	***	**		
5-8					80/130 RP	26/32	***	**		
As many as required					100/150RP	28/32	***	**		
Shop Welds	SHOP WELDS BY CREUSOT-LOIRE, WELD PROCEDURE NOT ON HAND									

*Argon shield and internal purge

**100% PT on root pass, after first 3 GTAW passes, and on intermediate pass each 25mm of SMAW welding. 100% RT on intermediate passes every 25mm and on final surface, 100% PT on final surface.

***Not Available

TABLE 2-12 SUMMARY OF PIPE WELD DETAILS FOR YR

TYPE OF WELD	Weld Process *	Electrode or Filler Metal Specification	Electrode Size **	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds										
layers:	a,c	a,c	a,c	a,c						
root					120/130 SP	14/16	***	PT	Stone & Webster ↓	9699 ↓
As many as required					70/100/130	18/20/22	***	RT & PT after final pass		
					80/110/135 RP	18/22/24	***			
Shop Welds	SAME AS FIELD WELDS									

*Argon shield and internal purge
**Electrode size depends upon thickness (T) of base metal
***Not Available..

TABLE 2-13 SUMMARY OF PIPE WELD DETAILS FOR OPPD

TYPE OF WELD	Weld Process*	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Field Welds										
layers:	a,c	a,c	a,c	a,c						
root &					60/100SP 70/120SP	10/15	2	**	Peter Kiewit Son's Co.	16A
1st SMAW					60/100 RP	22/25	1	**	↓	↓
2nd & 3rd					80/130 RP	23/26	1	**		
As many as required					80/130 RP	23/26	↓	**		

*Argon shield and internal purge
**RT and PT

TABLE 2-13 SUMMARY OF PIPE DETAILS FOR OPPD (cont'd)

TYPE OF WELD	Weld Process	Electrode or Filler Metal Specification	Electrode Size	Electrode Type	Current (amps) Polarity	Voltage (volts)	Number of Heats	Inspection Requirements	Manufacturer or Fabricator of Welds	Identification of Key Documents
Shop Welds	a,c	a,c	a,c	a,c						
groove	[ ]	[ ]	[ ]	[ ]	425 ± 10% RP	30 ± 10%	**	***	Combustion Engineering Inc. →	SAA-23 rev. 0 →
backgroove	[ ]	[ ]	[ ]	[ ]	180 ± 10% RP	25 ± 10%	**	***		

*Argon shield
**34 heats of weld filler metal
***RT & PT

3. TEST PROGRAM

Welding process, filler metal specification and heat treatment condition are the three major factors that determine the tensile and fracture toughness properties of welds. Examination of the Tables 2-1 through 2-13 shows that four welding processes, namely, Gas Tungsten Arc Weld (GTAW), Gas Metal Arc Weld (GMAW), Shielded Metal Arc Weld (SMAW) and Submerged Arc Weld (SAW), were used in the fabrication of primary coolant pipes. The welding processes GTAW and GMAW were used either in the deposition of overlay weld metal or in the root pass welding. In either case, the volume of metal deposited by these precesses are small and are less than about ten percent of the total volume of metal contained in any given weld joint. In other words, a large volume of the metal in any given joint was deposited by either the SMAW or SAW processes. For this reason, the SMAW and SAW processes were chosen for test. This choice was agreed to with the US NRC staff prior to the preparation of weld samples.

The weld metals used in the various welds are Inconel-182, SS-308, SS-308L, SS-309, SS-309L, SS-136 and SS-316L. Of these SS-308, SS-309, SS-316 and Inconel were chosen for test. The only significant difference between SS-308, SS-309 and SS-316 and SS-308L, SS-309L and SS-316L is in the carbon content. The carbon content of the former materials may be up to 0.08 percent by weight whereas the carbon content of the latter materials is specified to be below 0.03 percent. At the outset it was assumed that the variations in the carbon content would not significantly affect the properties that were sought in this test program. It has subsequently been shown, by an analysis of the carbon content, that this assumption was true. The two heat treatment conditions investigated are as welded and post weld heat treated (PWHT) conditions. Based on a combination of these parameters and prior discussion with the U.S. NRC, six weld samples were chosen for test. Table 3-1 shows the six weld samples, identified by SP-1 through SP-6, and the associated welding process, filler metal and heat treatment condition. Two tensile and three compact tension specimens were chosen for each weld sample.

The base metal plates for these weld samples was chosen to conform to ASTM-A240-Tp-316. The tensile properties of this material are comparable to those of reactor coolant system pipe base metal. The plate thickness was chosen to be 2-1/2 inches which is equal to the pipe wall thickness. In order to represent the long circumferential welds in the plants the length of the weld samples was chosen to be 48 in. long.

TABLE 3-1. WELD SAMPLE CHARACTERISTICS

a,c

Sample Number	Welding Process	Filler Metal	Condition	Tensile Specimens	Compact Specimens
SP-1	[ ]a,c	[ ]a,c	[ ]a,c	2	3
SP-2				2	3
SP-3				2	3
SP-4				2	3
SP-5				2	3
SP-6				2	3

4. FABRICATION OF FULL PENETRATION WELD SAMPLES

Figure 4-1 illustrates schematically the various parts of the weld sample and the orientation of the tensile and compact tension specimens. The fabrication of the weld samples began with the preparation of a detailed welding procedure for each of the samples. Two base metal plates, 18 in. x 48 in. x 2-1/2 in., were cut and a 22-1/2 degree bevel was machined on one end. The plates were set-up such that the two 22-1/2 degree faces faced each other with a separation of 1/2 in. The weld metal was deposited using a backing plate. The welds were radiographically examined. Where applicable, the radiography was carried out after heat treatment.

17,455-1

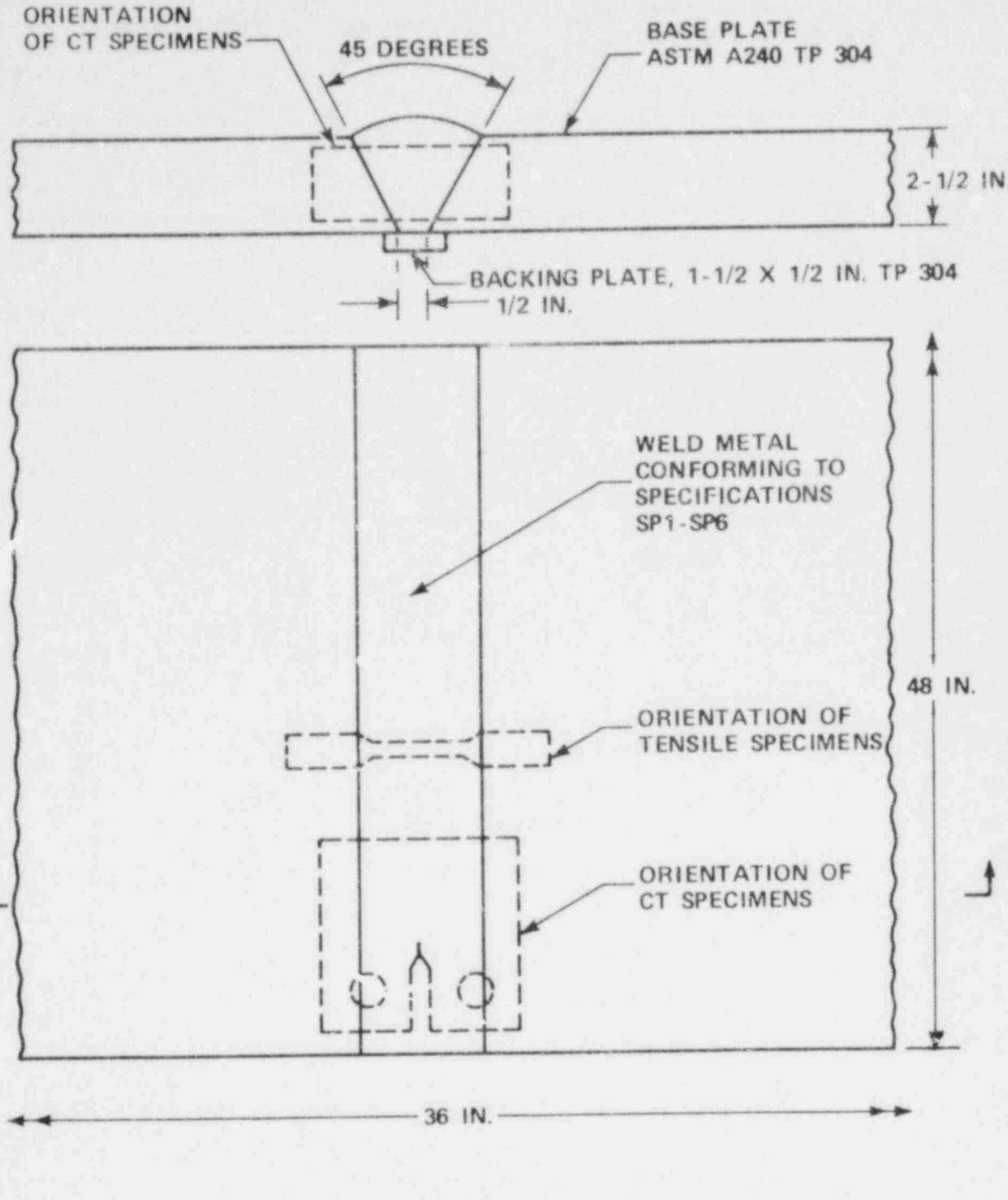

Figure 4-1 Weldment Configuration Showing the Orientation of Specimens

5. TEST RESULTS

Three 2 in. thick compact tension (CT) specimens and two standard ASTM 505 tensile specimens were machined from each weld sample. The orientation of specimens is shown in Figure 4-1. All of the specimens were tested at 600°F under static loading conditions following the procedure described in [1]. A chemical analysis of each of the weld samples was performed to determine the carbon content.

[ ]a,c

TABLE 5-1 TENSILE PROPERTIES OF WELD SAMPLES AT 600°F

Weld Sample Number *	Elastic Modulus KSI	0.2% Yield Strength KSI	Ultimate Strength KSI	% Elongation	% Reduction in area	% Weight Carbon Content
	a,c	a,c	a,c	a,c	a,c	a,c
SP-1						
SP-2						
SP-3						
SP-4						
SP-5						
SP-6						

* See Table 3-1 for discription of samples.

TABLE 5-2 2T Compact Tension Specimen Test Results at 600°F

Specimen Number	J in-lb/in^2	Δa in
SP1-3	[ ] a,c	[ ] a,c
SP1-1		
SP1-2		
SP2-3		
SP2-1		
SP2-2		
SP3-1		
SP3-2		
SP3-3		
SP4-3		
SP4-2		
SP4-1		
SP5-2		
SP5-1		
SP5-3		
SP6-3		
SP6-1		
SP6-2		

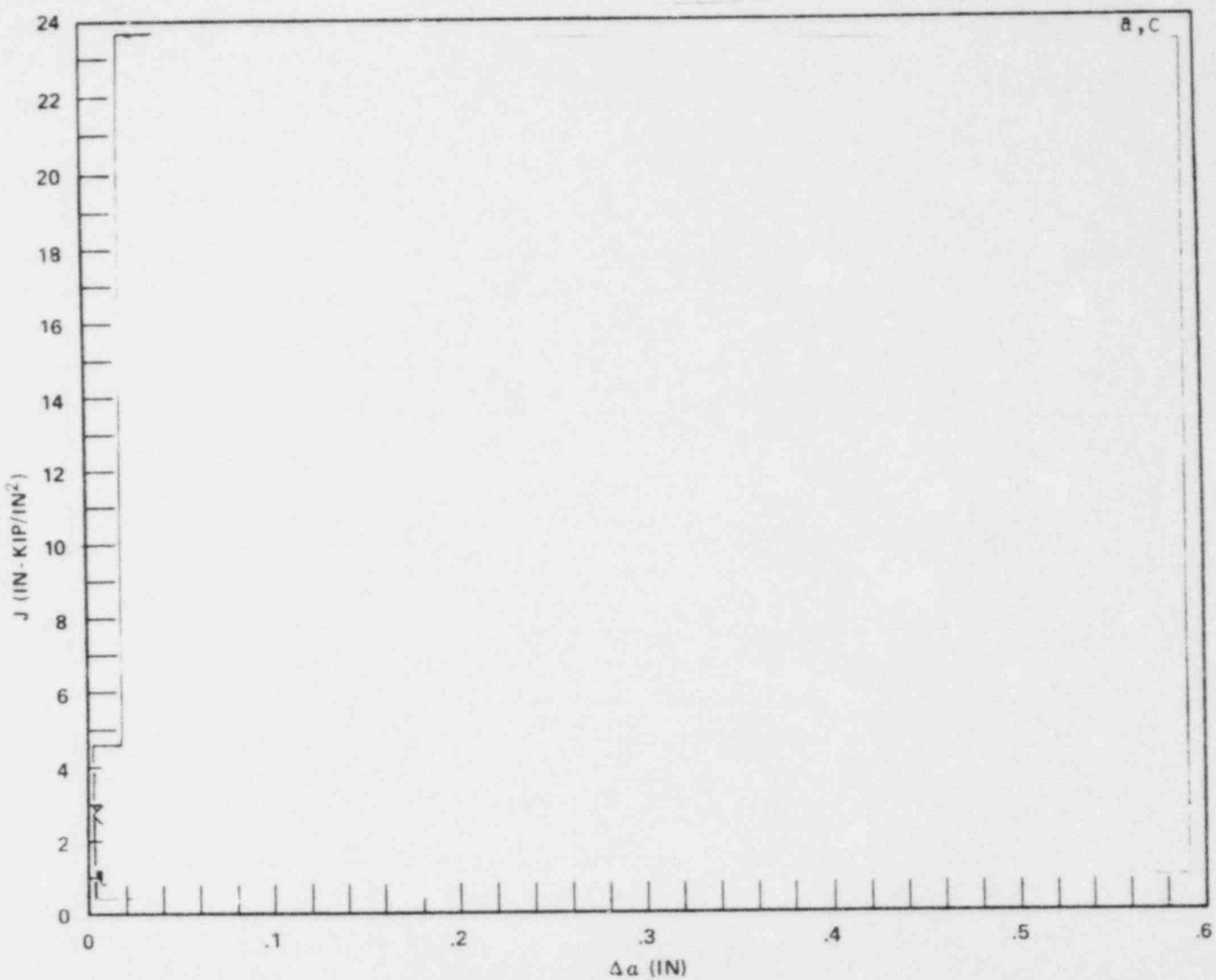

Figure 5-1 J-Resistance Curve for Primary Piping Base and Weld Metal

6. DISCUSSION & RESULTS

a,c

7. SUMMARY AND CONCLUSION

The material, design and fabrication details of all the full circumferential welds in the reactor coolant piping system of the sponsoring utilities have been reviewed and summarized. Based on a careful examination of all the factors that would influence the tensile and fracture toughness characteristics of the welds in consideration, six different weld samples were tested. A detailed specification was developed for welding each sample. Out of each sample, two tensile and three 2 inch thick compact tension specimens have been machined and tested following the standard or the state-of-the-art procedure under static loading condition at 600°F temperature.

[ ] a,c

[1] Palusamy, S.S. and Hartman, A.J., Mechanistic Fracture Evaluation of Reactor Coolant Pipe Containing a Postulated Circumferential Through-Wall Crack, WCAP-9558-Rev. 2, Proprietary Class 2, January 1981.

APPENDIX A

FRACTURE TOUGHNESS OF STAINLESS STEEL WELDMENTS AT 600°F

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Materials Testing and Evaluation Department

Research Report 80-5D3-SSJRC-R1
Proprietary Class: 2

September 9, 1980

FRACTURE TOUGHNESS OF STAINLESS STEEL WELDMENTS AT 600°F

J. D. Landes
Structural Behavior of Materials Department

A. J. Bush and R. B. Stouffer
Materials Testing and Evaluation Department

ABSTRACT

Fracture toughness tests were conducted on five stainless steel weldments and one Inconel weldment at 600°F using the J-R curve format to determine whether the weld fusion zone has equivalent toughness to

[ ]a,c

INTRODUCTION

In a previous study stainless steel piping material was tested at 600°F to determine fracture toughness in a J-R curve format. Tests were conducted both under conventional and dynamic loading rates. The material proved to be of sufficient toughness with dynamically loaded tests exhibiting somewhat higher toughness than those loaded at a conventional rate so conventional rate testing was considered to provide a conservative lower bound. The piping material was both cast and wrought fabrication and constituted a base metal condition. A question was raised as to whether a weld fusion zone would have a toughness level comparable to the base metal. Therefore a testing program was initiated to measure the toughness of weld material.

Six different weldments were prepared. Fracture toughness tests were conducted on three specimens from each heat to compare points on the J-R curve with tests from the base metal. All tests were conducted at a conventional loading rate because the resulting data is considered to be conservative. In this report the results from these tests on weld metal are presented and compared with previous results from base metal.

MATERIAL AND PROCEDURE

The material consisted of six different weldments identified by SP-1 through SP-6. Weldments SP-1 through SP-4 and SP-6 were made of stainless steel whereas SP-5 was made of Inconel. Two inch thick compact (2T-CT) specimens were machined and precracked. The tests were conducted at 600°F in a manner similar to the J_{Ic} test procedure; the loading rate was conventional.[2] A detailed description of this procedure was given in a previous report.[1]

Duplicate tensile tests were conducted for each weldment at 600°F using 1/4 inch diameter tensile specimens.

RESULTS

The results from the tensile tests are given in Table 1 and Figure 1. The results are fairly uniform with the exception of Inconel weldment SP-5 showing a higher ultimate strength and percent elongation.

The results from the toughness tests are given in Table 2 and are plotted in the form of J versus crack extension, Δa, on individual plots for each weldment, Figures 2-7. A best fit straight line for each set of three points was determined by the least squares method and plotted on each figure. These lines are not the same as those used to determine J_{Ic} by the proposed ASTM procedure because the number of points and Δa values do not conform to this procedure.[2] Values of Δa were taken well beyond the limit for J_{Ic} determination so that a substantial portion of the R curve could be developed.

All of the points for the six weldments are presented on a single plot, Figure 8, where they are compared with the upper and lower bound lines for the base metal specimens tested at a conventional rate. The best fit straight lines are all presented on a single plot, Figure 9, where they are again compared with the conventional rate bounds.

DISCUSSION

a.c

[ ]a,c

The objective of this study was to observe the relative position of the points on the R curve rather than to develop complete R [ ]a,c

CONCLUSION

a,c [ ]

REFERENCES

1. J. D. Landes, S. S. Palusamy, A. J. Bush and L. J. Ceschini, "Fracture Toughness of 316 Stainless Steel Piping Material at 600°F," Westinghouse Research Report 79-7D3-PIPRE-R1.

2. G. A. Clarke, et al., "A Procedure for the Determination of Ductile Fracture Toughness Values Using J Integral Techniques," Journal of Testing and Evaluation, JTEVA, Vol. 7, No. 1, January 1979, pp. 49-56.

TABLE 1

TENSILE RESULTS FOR WELDMENTS
(600°F)

Specimen No.	Yield Strength (ksi)	Ultimate Strength (ksi)	% Elongation (1 inch)	% RA	Elastic Modulus (ksi)
					a,c
SP1-4					
SP1-5					
SP2-4					
SP2-5					
SP3-4					
SP3-5					
SP4-4					
SP4-5					
SP5-4					
SP5-5					
SP6-4					
SP6-5					

Q = Quarter Break

CONCLUSION

a,c [ ]

REFERENCES

1. J. D. Landes, S. S. Palusamy, A. J. Bush and L. J. Ceschini, "Fracture Toughness of 316 Stainless Steel Piping Material at 600°F," Westinghouse Research Report 79-7D3-PIPRE-R1.

2. G. A. Clarke, et al., "A Procedure for the Determination of Ductile Fracture Toughness Values Using J Integral Techniques," Journal of Testing and Evaluation, JTEVA, Vol. 7, No. 1, January 1979, pp. 49-56.

TABLE 1

TENSILE RESULTS FOR WELDMENTS
(600°F)

a,c

Specimen No.	Yield Strength (ksi)	Ultimate Strength (ksi)	% Elongation (1 inch)	% RA	Elastic Modulus (ksi)
SP1-4					
SP1-5					
SP2-4					
SP2-5					
SP3-4					
SP3-5					
SP4-4					
SP4-5					
SP5-4					
SP5-5					
SP6-4					
SP6-5					

Q = Quarter Break

TABLE 2

J and Δa Values for Weldments

(600°F)

Specimen No.	J $(\frac{in.-lb}{in.^2})$	Δa (in.)
SP1-3	a,c	a,c
SP1-1		
SP1-2		
SP2-3		
SP2-1		
SP2-2		
SP3-1		
SP3-2		
SP3-3		
SP4-3		
SP4-2		
SP4-1		
SP5-2		
SP5-1		
SP5-3		
SP6-3		
SP6-1		
SP6-2		

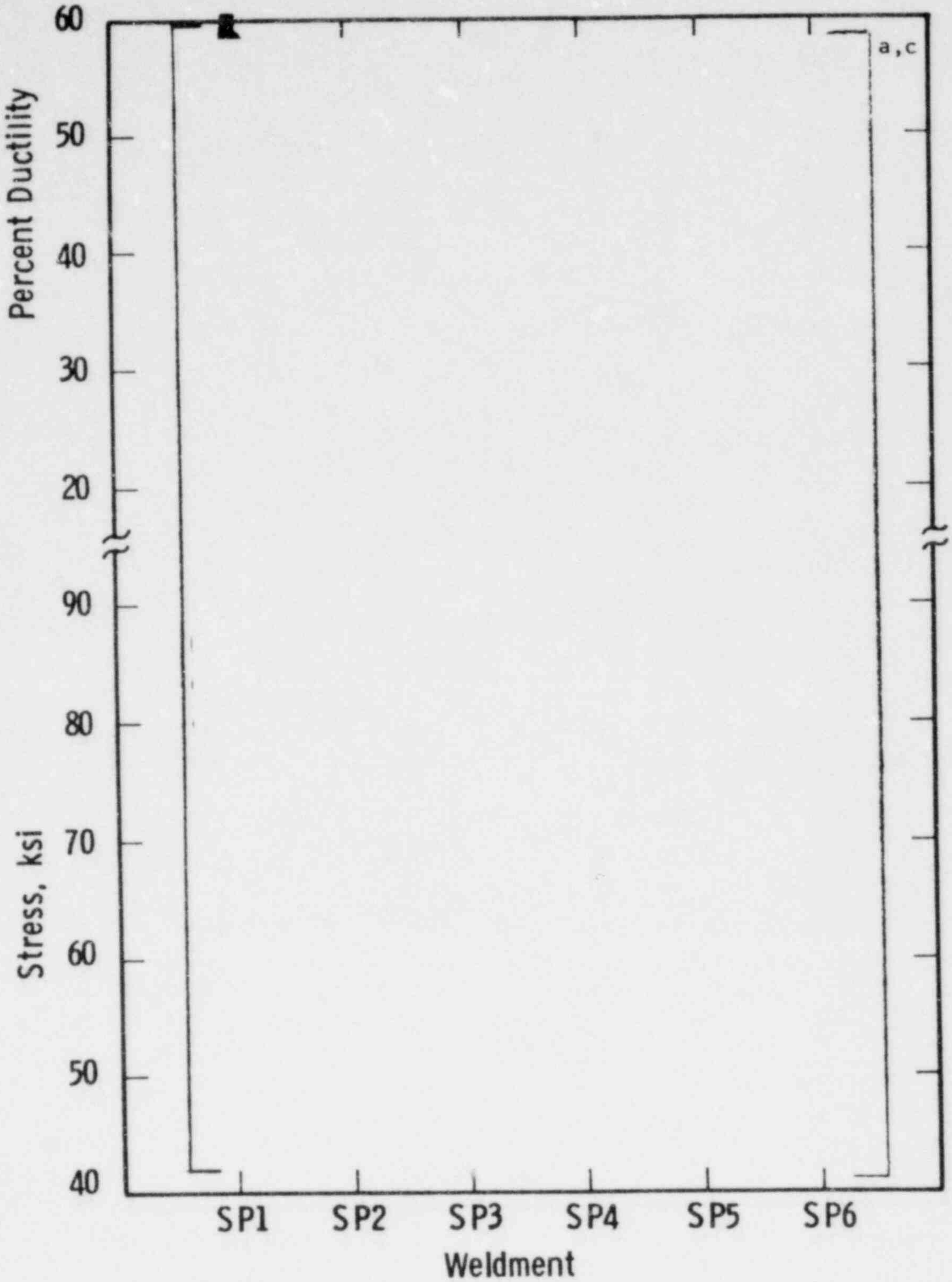

Figure 1. Tensile Properties of the Stainless Steel and Inconel Weldments of 600°F

J. Landes
l.t. - e.s. 10-2-80

Curve 724658

Curve 724659-A

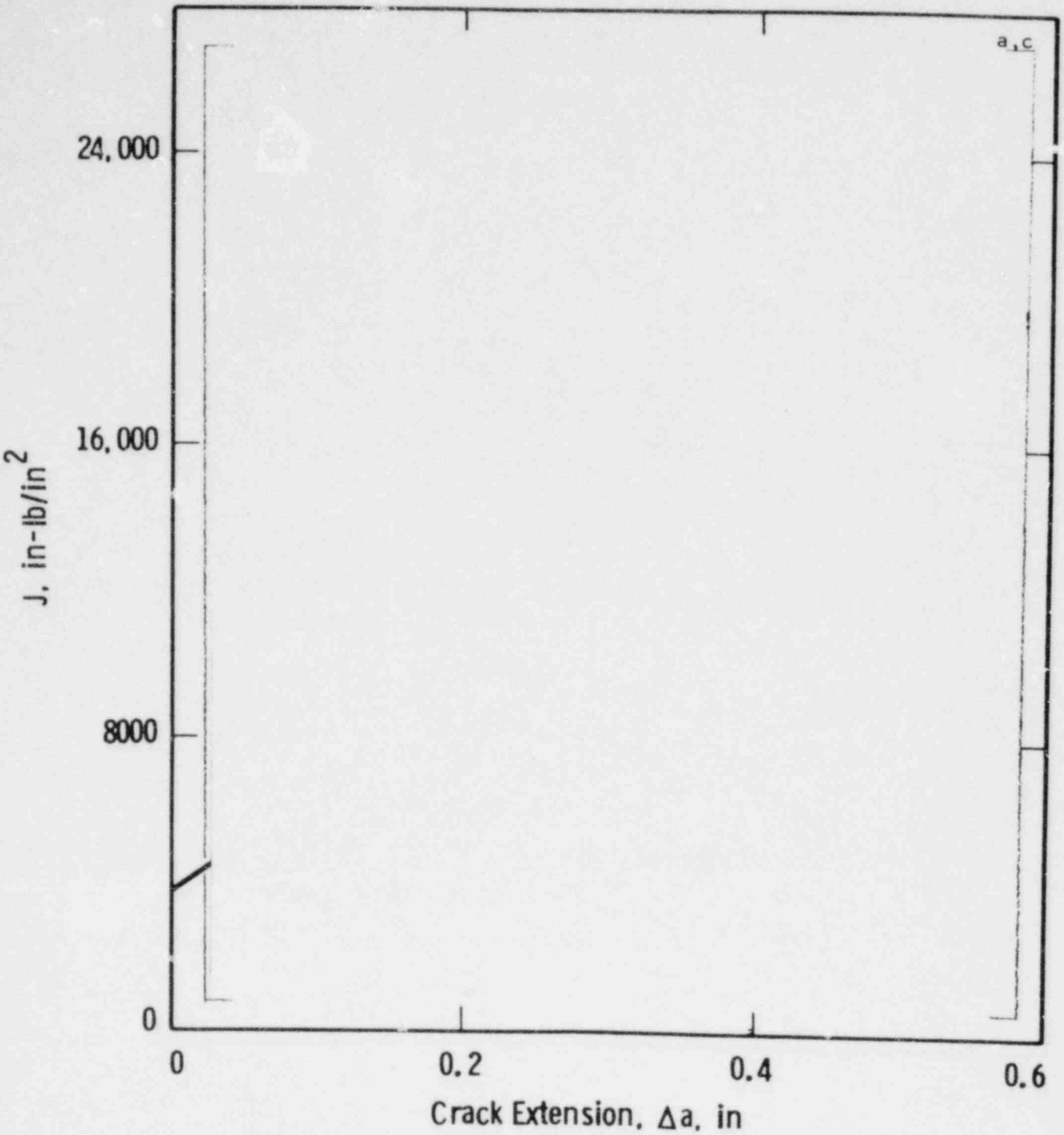

Figure 2. J versus Δa for the Stainless Steel Weldment SP1 at 600°F

J. Landes
l.t. - e.s. 10-2-80

Curve 724659-A

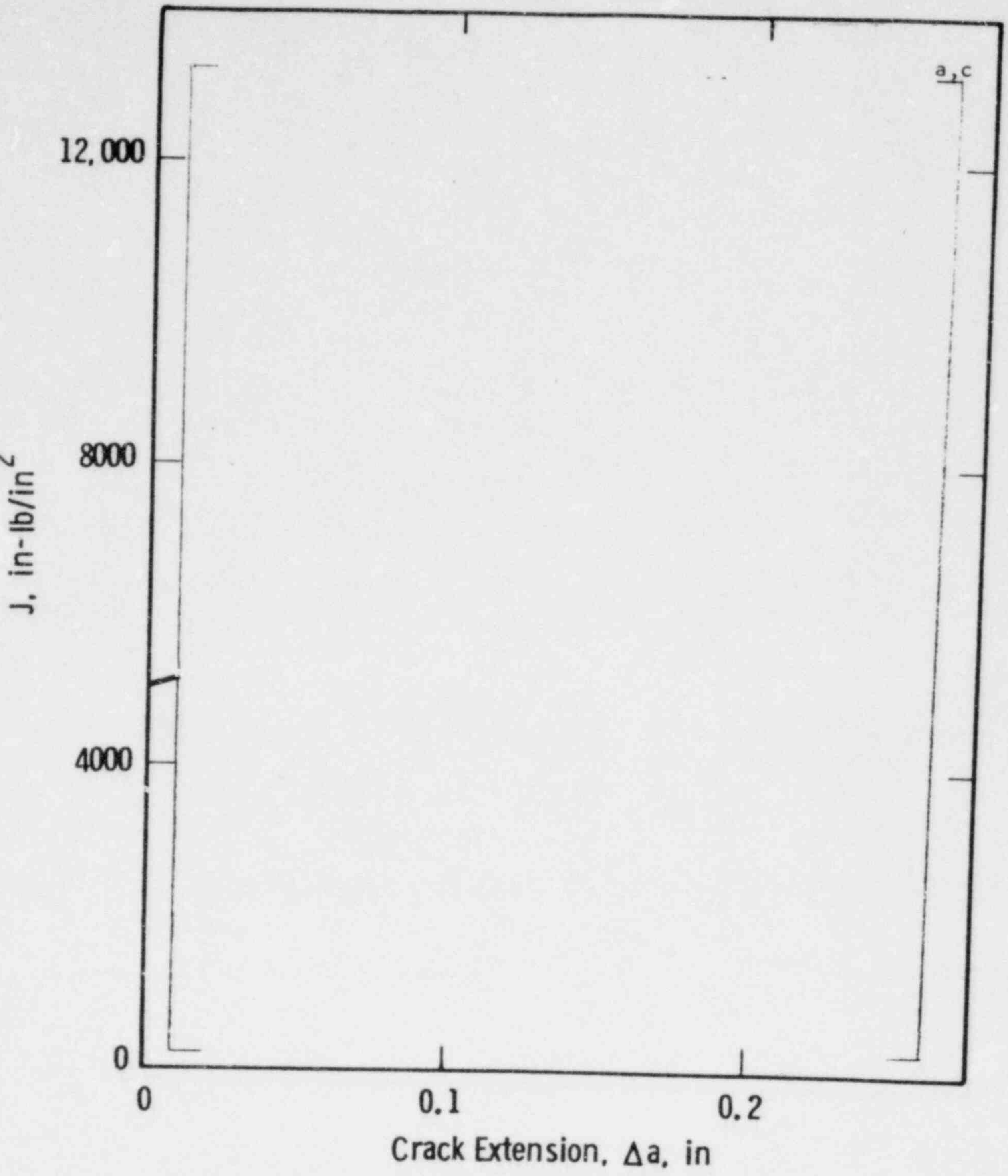

Figure 3. J versus Δa for the Stainless Steel Weldment SP2 at 600°F

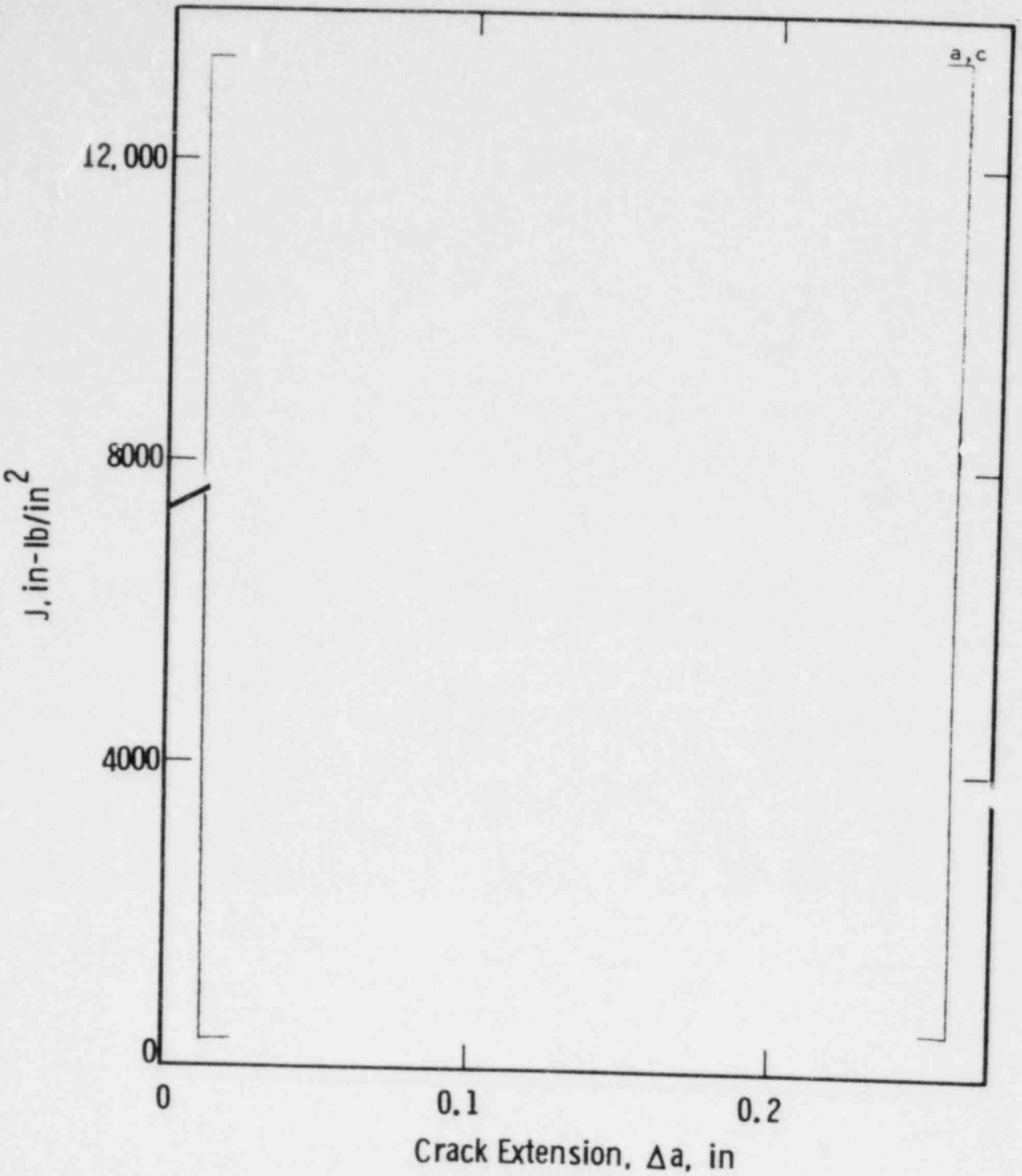

Figure 4. J versus Δa for the Stainless Steel Weldment SP3 at 600°F

J. Landes
l.t. - e.s. 10-2-80

Curve 724662-A

Curve 724661-A

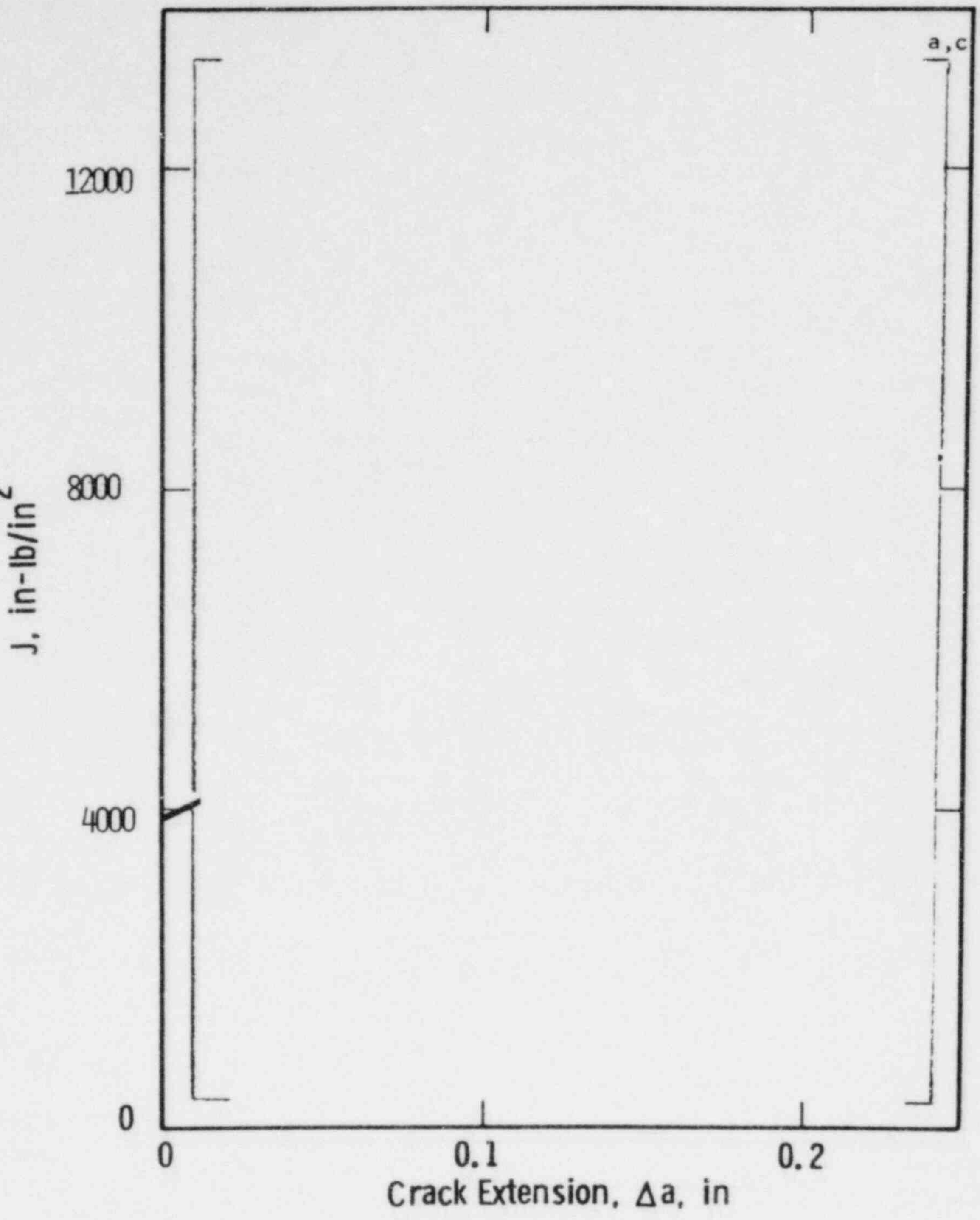

Figure 5. J versus Δa for the Stainless Steel Weldment SP4 at $600^{o}F$

J. Landes
l.t. - e.s. 10-2-80

Curve 724661-A

Curve 724656-A

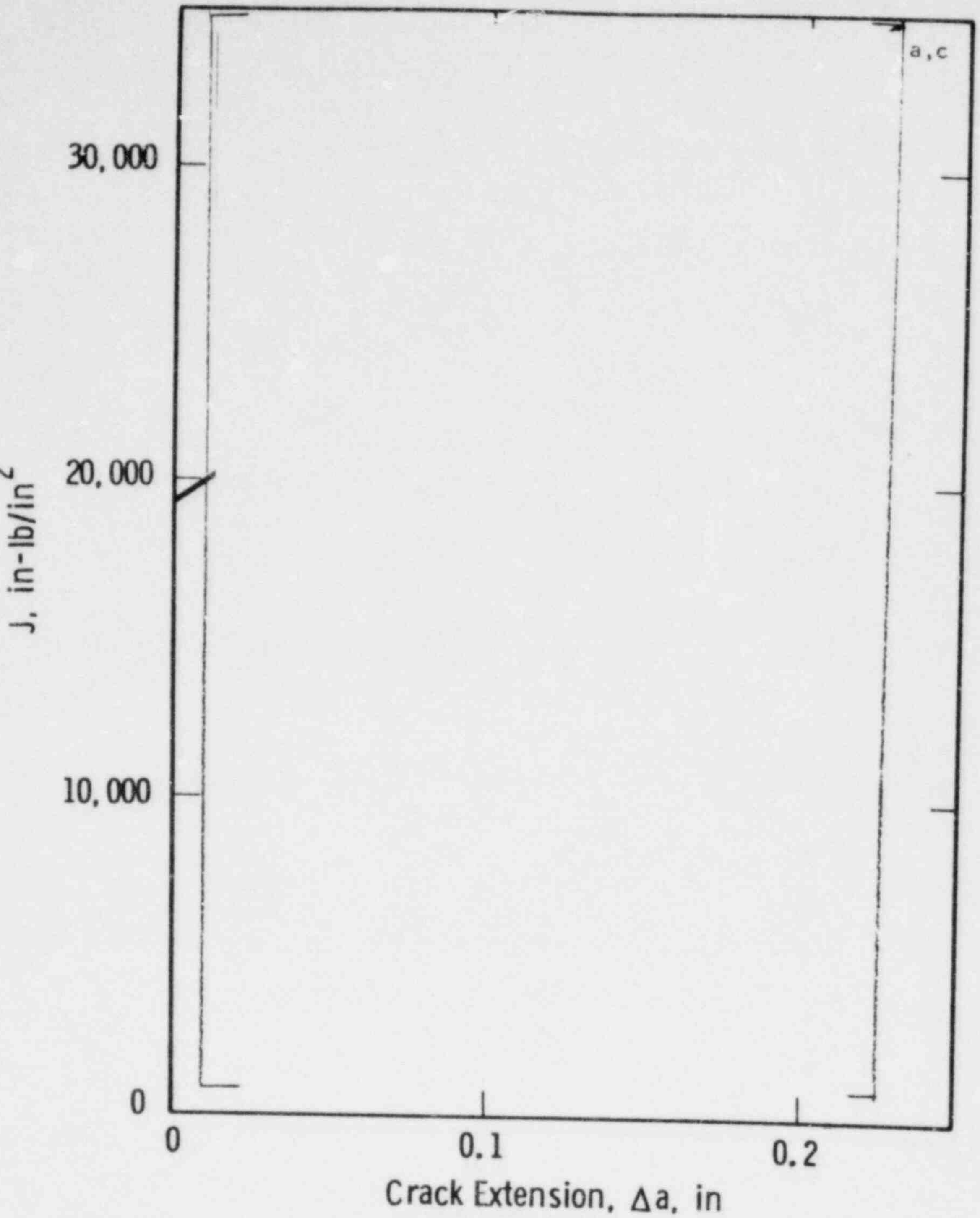

Figure 6. J versus Δa for the Inconel Weldment SP5 at $600^{o}F$

J. Landes
l.t. - e.s. 10-2-80

Curve 724656-A

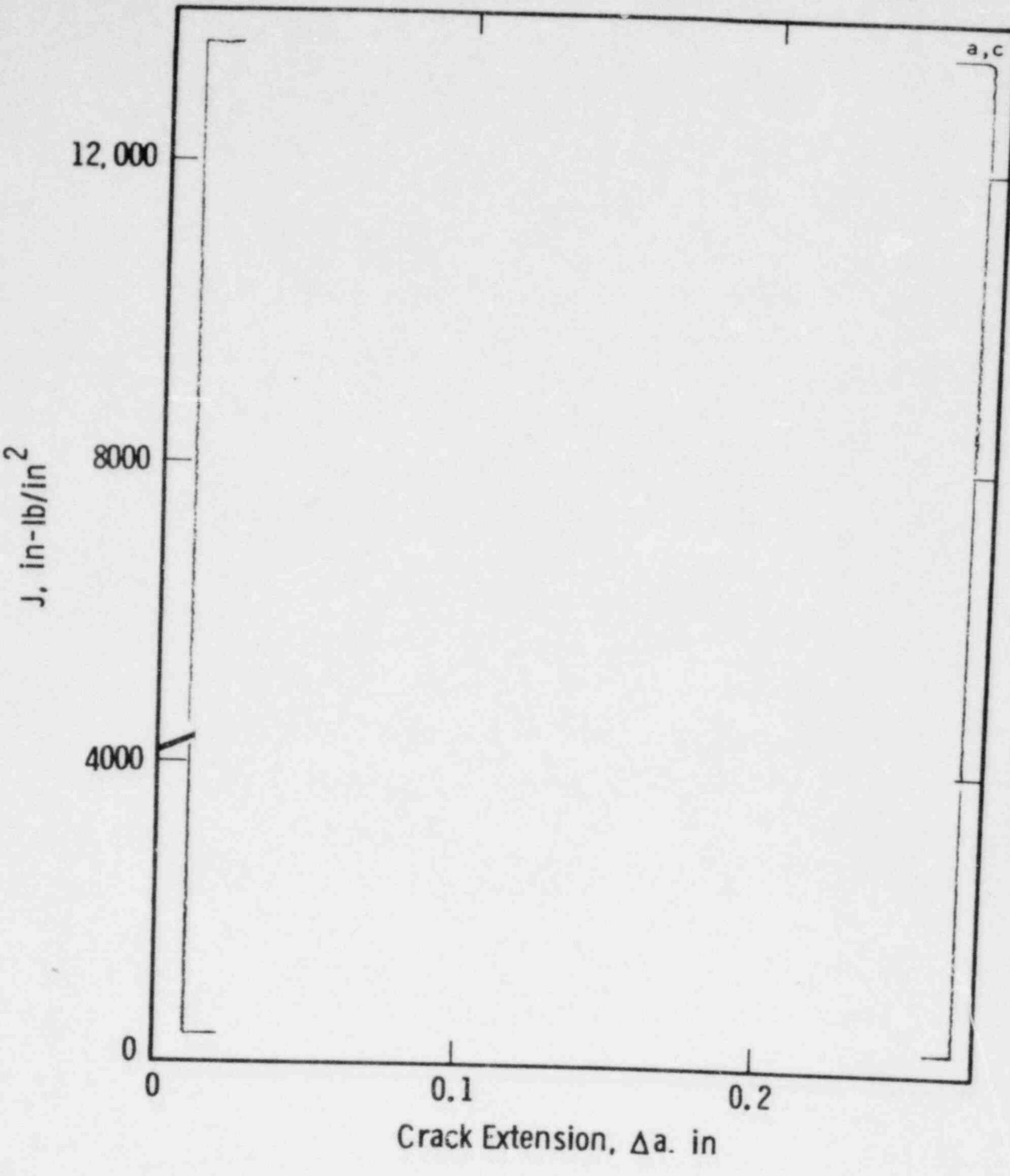

Figure 7. J versus Δa for the Stainless Steel Weldment SP6 at 600°F

J. Landes
l.t. - e.s. 10-2-80

Curve 724655-A

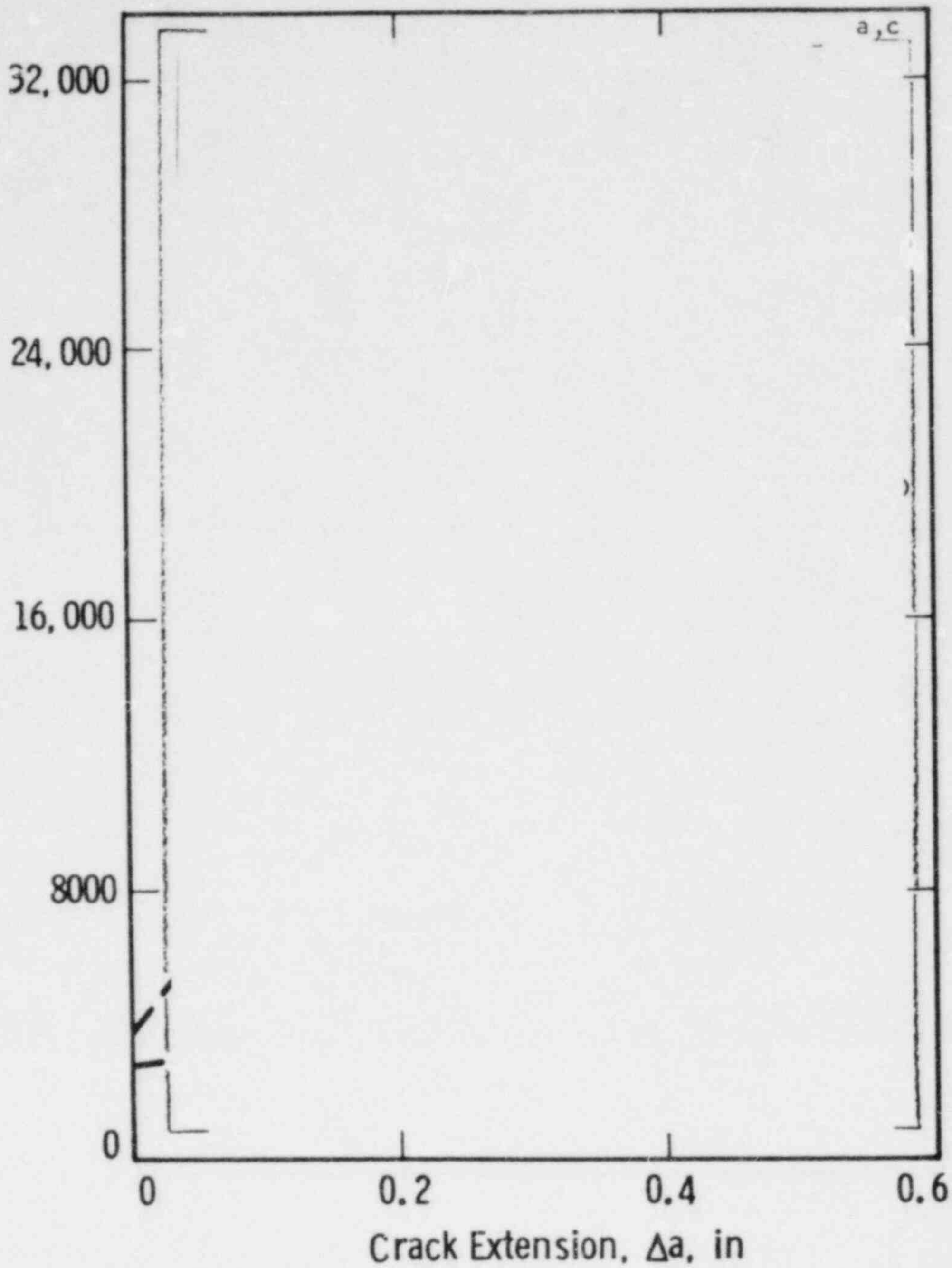

Figure 8. J versus Δa for the Stainless Steel (SP1-SP4, SP6) and Inconel (SP5) Weldments at $600^{\circ}F$

J. Landes
l.t. - e.s. 10-2-80

Curve 724660-A

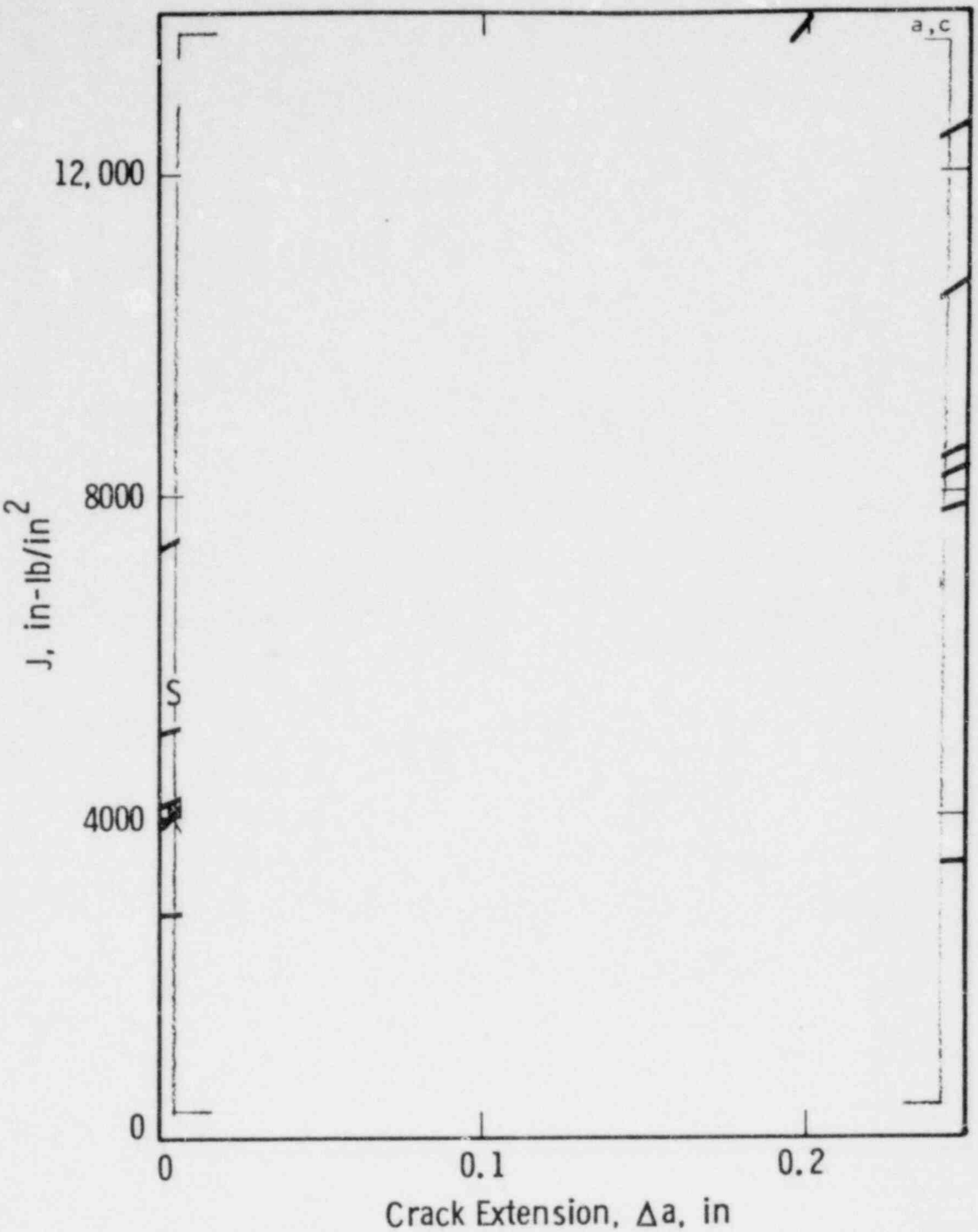

Figure 9. Best Fit Linear Curves to the Three Points on J versus Δa Curves for Each Stainless Steel Weldment

J. Landes
l.t. - e.s. 10-2-80

Curve 72

Landes
- C.S. 10-2-80

Curve 724653-A

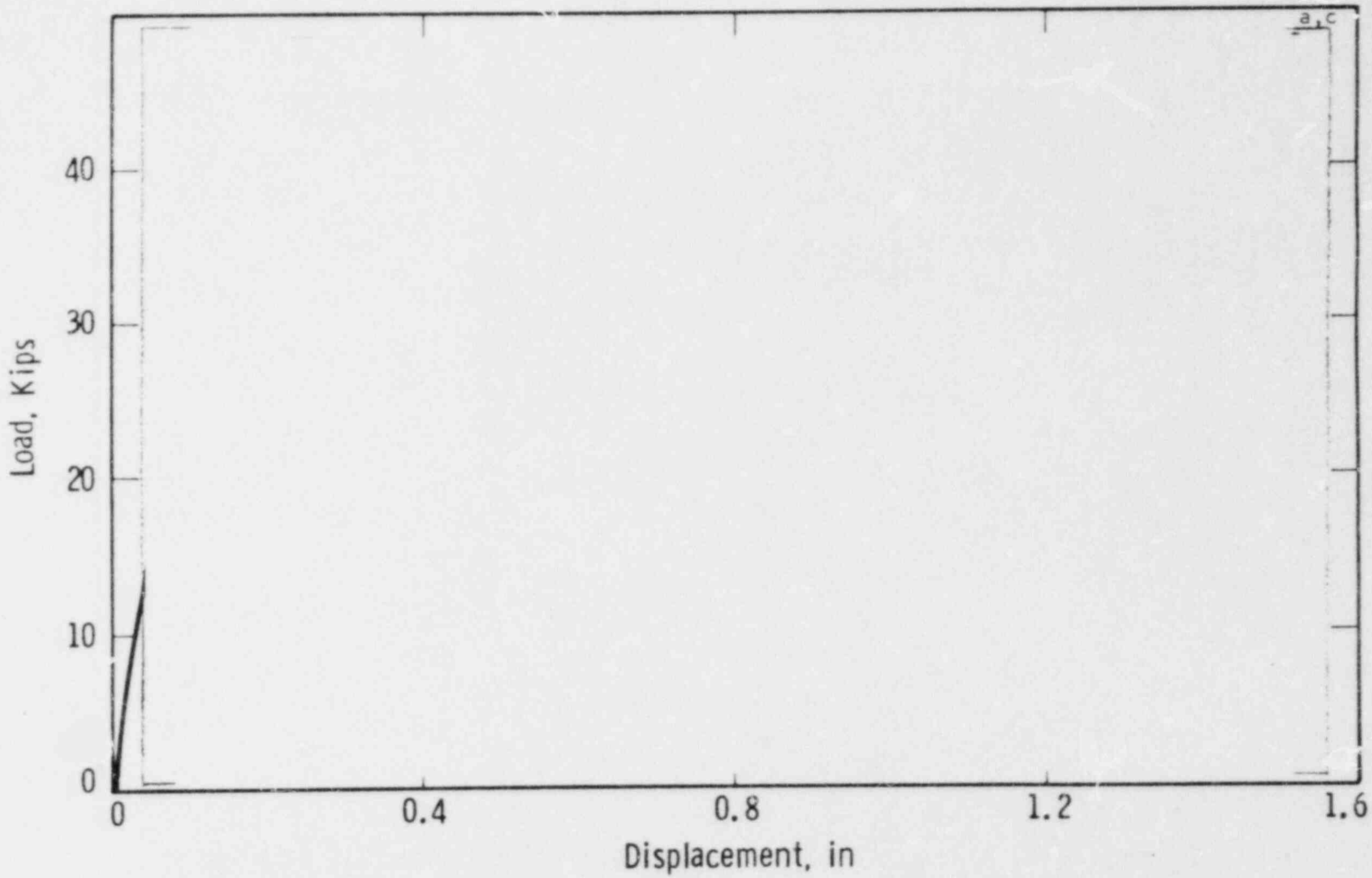

Fig. 10 - Figure 10. Load versus Displacement for Three Specimens of Stainless Steel (SPI-1, SPI-2) and Inconel (SP5-3 Weldments at 600^{o}F

Curve 724653-A

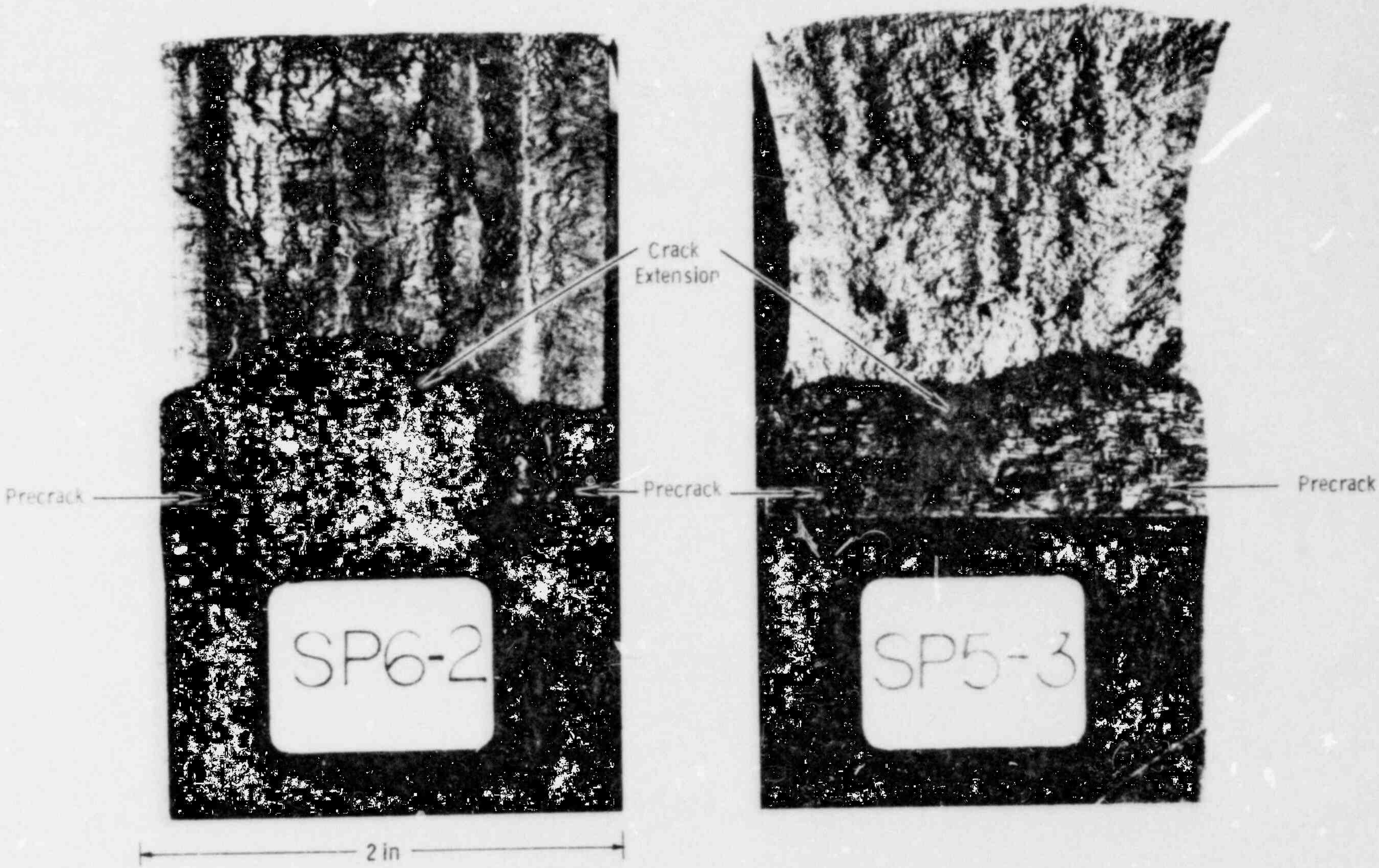

Figure 11. Fracture Surfaces for Two Specimens of Stainless Steel (SP6-2) and Inconel (SP5-3) Weldments Tested at 600°F

RM-86117